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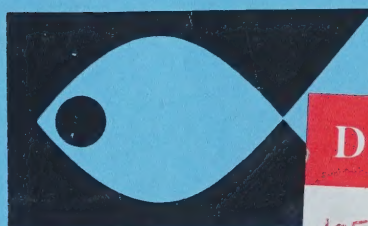
THE PRESENCE AND IMPLICATION OF FOREIGN ORGANISMS IN
SHIP BALLAST WATERS DISCHARGED INTO THE GREAT LAKES.

VOLUME 1. / Bio-Environmental Services Ltd. 1981.

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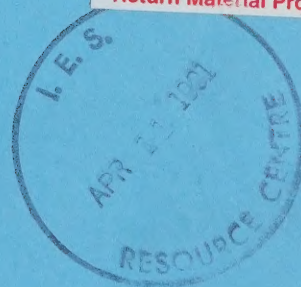


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THE PRESENCE AND IMPLICATION OF FOREIGN ORGANISMS
IN SHIP BALLAST WATERS
DISCHARGED INTO THE GREAT LAKES
- VOLUME 1 -

Mr. J. S. Sweeney
278
11th Floor
Place Vincent Massey
Ottawa, Quebec
K1A 1C9

Dear Mr. Sweeney:

Prepared by

BIO-ENVIRONMENTAL SERVICES LTD.

Re: File No. 7
Foreign Organisms in Ship Ballast Waters Discharged
into the Great Lakes

I am pleased to present our report on the ballast water project
described in the IJC Contract #1980-11304-0-0167. The effort
expended in this study was successful in providing a preliminary
assessment of the potential for impact of ballast water organism
discharge to the Great Lakes and the direction that future
investigation should take.

for

THE WATER POLLUTION CONTROL DIRECTORATE

ENVIRONMENTAL PROTECTION SERVICE

ENVIRONMENT CANADA

March 1981



**Bio-Environmental
Services Ltd.**

247 Armstrong Ave. unit 10,
Georgetown Ontario,
L7G 4X6, (416) 877-0107

March 2, 1981

Mr. J. Schormann
EPS
13th Floor
Place Vincent Massey
Hull, Quebec
K1A 1C8

Dear Mr. Schormann:

Re: File No. FED.80135 - The Presence and Implication of
Foreign Organisms in Ship Ballast Waters Discharged
into the Great Lakes

I am pleased to present our report on the ballast water project described in the DSS Contract #36SS.KE204-0-0167. The effort expended in this study was successful in providing a preliminary assessment of the potential for impact of ballast water organism discharge to the Great Lakes and the direction that future investigations should take.

Our overall assessment is that organisms are alive in ship ballast water when it is discharged. The potential, therefore, exists for foreign organisms to enter the Great Lakes system in a viable state. The potential for any particular foreign organism to survive and create a detrimental impact on the Great Lakes ecosystem will depend on the ability of the organism to adapt to the new environment. Successful establishment of an organism will depend on the density (numbers) originally discharged from a ballast tank and their ability to sustain a reproducing population. Several viable, marine and freshwater organisms, nonendemic to the Great Lakes or the St. Lawrence estuary were found in the samples and appear to meet the above criteria.

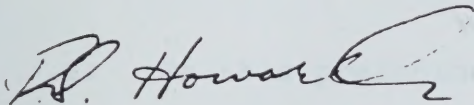
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The report is divided into two volumes. The text is contained in Volume 1 and the report data and appendix are presented in Volume 2. For convenience, a concise summary and our recommendations precede the main text of the report.

The cooperation and assistance of yourself, as well as other members of Environment Canada, are greatly appreciated.

Yours truly

BIO-ENVIRONMENTAL SERVICES LTD.



R. S. Howarth
Operations Manager

RSH:mat
Encl.

SUMMARY

1. A study, funded by the Environmental Protection Service and the Department of Supply and Services, was conducted in 1980. The purpose was to determine the water quality of foreign ship ballast water and to assess the potential for impact of the introduction of nonendemic aquatic organisms on the Great Lakes ecology.
2. In this preliminary study, the results were based on grab samples taken from manhole areas of the ballast tanks and from the discharge side of ballast pumps. Sediment at the base of the ballast tanks was not sampled.
3. Between August 25 and October 31, 1980, a total of 55 ship ballast waters, representing 10 geographic regions of origin in the world, were sampled as the vessels entered the St. Lawrence-Great Lakes system.
4. The water quality of the samples was within a normal accepted level that would not inhibit a broad range of aquatic organisms from surviving in the ballast tanks.
5. One ballast tank sample contained raw sewage, indicating that a potential health hazard exists if this material is deballasted within the vicinity of populated areas

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which utilize the Great Lakes as a source of water supply.

6. The major component of the study consisted of the identification and enumeration of aquatic flora and fauna ($>80\mu$) found in the ballast samples, and the assessment of the potential for impact of these organisms on the Great Lakes system, if released.
7. Almost all ballast tanks sampled contained aquatic organisms in a viable state. It was apparent that organisms were capable of surviving in ballast tanks for extended periods of time up to at least 18 days. Ballast waters obviously can play an important role in the transport of aquatic organisms from one region of the world to another.
8. The results of the study clearly indicate that non-indigenous and nonendemic aquatic species are being imported into the Great Lakes system.
9. The majority of aquatic flora found in the samples consisted of freshwater and marine phytoplankton. Macrophytes, although present in the samples, were fragmented

and unidentifiable. The nanoplankton fraction of the phytoplankton community form an important part of the biota. However, these organisms were not part of the intended program, and therefore, received only a cursory examination.

10. Over 150 distinct genera and species of phytoplankton were identified in the samples. Many are universally recognized as problem species, and were representatives of most algal classes. Species of marine phytoplankton have been identified as having successfully invaded the Great Lakes and the capability is present in other marine species currently nonendemic to the system to do the same.
11. Approximately 56 distinct aquatic invertebrate fauna were identified in the samples. All the freshwater fauna probably were not indigenous to the Great Lakes, but could have the potential to become established. Several marine organisms are recognized problem species, capable of establishing themselves in the St. Lawrence estuary.

12. There are numerous examples of innocuous organisms in their native environment becoming serious pests in a new habitat. The absence of natural enemies and other environmental controls permit the introduced species to proliferate and develop into serious problem organisms. Therefore, it is very difficult to assess the potential impact of this type of organism when introduced to a new habitat without conducting extensive research. A number of nonendemic aquatic organisms found in the ballast water samples and capable of establishing themselves in the Great Lakes are in this category.
13. Some geographic zones or water types were not encountered in the study. For those geographic regions that were represented in the ballast samples, periodicity of organism distribution and occurrence (diurnality, reproductivity, etc.) would prevent all possible organisms being present in any one ballast sample. In addition, organism blooms are staggered throughout the year, indicating that one sampling period will not produce the complete range of potential taxa.

14. No single species list has been compiled for aquatic organisms present in the Great Lakes and the ecology of the majority of organisms has not been documented. To conduct a comprehensive survey and assessment, a collection of the taxonomic and distributional literature for the Great Lakes and other major geographic areas will be necessary.

RECOMMENDATIONS

As a result of undertaking the present survey, it is recommended that the ballast water sampling program be continued with the following modifications:

1. A spring sampling program should be conducted in an effort to account for the seasonal periodicity of aquatic organism communities. The logical time to begin the survey would be when the St. Lawrence Seaway opens in April;
2. An effort should be made to obtain ballast samples from ships that ballasted in foreign areas which were not encountered in the present study, and especially from vessels containing foreign freshwater ballast;
3. The present study did not investigate sediments. However, any future sampling program should consider the sediment because, if present, it may contain the majority of aquatic organisms in a ballast tank. Eggs, cysts, benthic organisms, and settled plankton because of lack of light in the ballast tank, may reside in the bottom of the tank;
4. The present study indicated that several marine organisms may have the potential to become established in the St. Lawrence estuary. As has occurred in Europe, this estuary may become a new habitat for organisms with the potential

to ultimately adapt and invade the Great Lakes. It is recommended that these organisms be included in any future survey;

5. Ballast water mixing and, therefore, the mixing in the ballast tanks of organisms from more than one habitat, is probable based on the results of the present study. Complete log details regarding ballasting should be obtained whenever possible;
6. A number of biological groups of organisms were not sampled in this study. Therefore, in addition to netplankton, consideration should be given to the identification and potential impact of microbes, nanoplankton, parasites and higher organisms.

In addition to a continuation of the ballast water sampling program, two other areas require consideration:

1. The compilation of a comprehensive species list of organisms in the Great Lakes;
2. A literature review of foreign problem aquatic organisms and their ecology with respect to their potential of becoming a problem organism if introduced to the Great Lakes.

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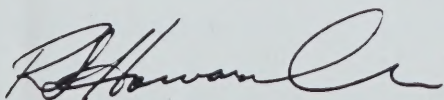
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BIO-ENVIRONMENTAL SERVICES LTD.



R. S. Howarth
Operations Manager

GLOSSARY OF TERMS

- Akinetes: resting spores.
- Coenobe: a colony of separate organisms or structures united by a common investment.
- Conspecific: belonging to the same species.
- Commensal: an organism living with another and sharing the food, both species as a rule benefiting by the association.
- Ecospecies: an ecological race or subspecies which shows physiological differences brought about by environmental influences; they often exhibit reduced fertility.
- Ecotype: a habitat type of plant; a sub-unit of the ecospecies produced by the reactions to its particular environment.
- Endophytic: living in cavities of other plants.
- Epiphyte: a green plant which is attached to or depends upon another plant for physical support but is able to manufacture its own food.
- Exotic: not indigenous; foreign.
- Indigenous: living naturally in an area; native; not introduced.
- Lorica: a hard protective case or shell, as the entire silicious covering of the frustule in diatoms.
- Mycosis: the growth of parasitic fungi in any part of the body; the disease caused by such fungi.
- Myxomycetes: the slime molds; fungi.
- Parthenogenesis: the production of true spores or seeds without fertilization.

INTRODUCTION

The unexpected, and sometimes intentional, importation of organisms of foreign origin has resulted in the establishment of many disease and nuisance organisms throughout the entire world. In many instances, an exotic organism has been so successful in establishing itself in a new environment that the enormous and rapid increase in its numbers has created an ecological explosion, the impact of which has often resulted in disastrous consequences for other organisms in the community.

Classic or historical examples of foreign organisms which have been imported into North America and have the potential to cause ecological disasters are numerous. Bubonic plague species have become established in the western regions of Canada and the United States; but, fortunately, few outbreaks in man have occurred (Link, 1955). The fungus, *Endothia parasitica*, which is believed to have been introduced into North America on Asian nursery plants, devastated the American chestnut (*Castanea dentata*) population. It is ironic that another foreign species, the Chinese chestnut (*C. mollissima*), which is immune to the parasite, was introduced to replace the American species (For. Comm., 1950; Metcalfe and Collins, 1911; Ulm, 1948). The Dutch elm disease, which results from the combined action of insects and a fungus, *Cerastomella ulmi*, invaded North America in the early part of this century. It has been so successful that it has essentially eliminated one of America's best shade trees

from many parts of eastern North America (Brewer, 1941; Collins, 1938; For. Comm., 1938). The European starling (*Sturnus vulgaris*), which was introduced into North America, began breeding successfully in 1891, and has now penetrated almost all regions of Canada and the United States (Cooke, 1928).

The unintentional importation and establishment of disease and nuisance organisms of foreign origin has long been a recognized problem in agriculture and medicine. For both these areas, efficient screening and quarantine procedures have been developed. Interprovincial and transborder movement of agricultural disease organisms, such as the Root Node Nematode and the various grass crop rusts, now rarely occur. In medicine, with the recent rapid influx of immigrants from eastern and tropical countries, the potential risk of establishment of previously unscreened species is very real.

The introduction of foreign aquatic species into North America has only recently come under close scrutiny. Over the last ten years, Canada is known to have been the recipient of aquatic plant and animal species of foreign origin from undetected sources. Many of the species are now established in our waterways. In some instances, these organisms have radically out-competed native species to the point of becoming an ecological threat or nuisance. Severe infestations of aquatic weeds,

such as the Eurasian watermilfoil, *Myriophyllum*, from the United States and Asia, for example, are now clogging our waterways across the country. Navigational, recreational and fishery uses, in many areas, are seriously impaired. Effective control measures are unknown and the problem is worsening at an increasing rate.

Similarly, in the Great Lakes and East Coast regions, unchecked migration and importation of certain fish species have resulted in the destruction of native species habitat and the development of disease. Coho salmon (*Onchorynchus kisutch*) and rainbow trout (*Salmo gairdneri*), both west coast fish species, have been introduced to the Atlantic region, and may have the potential to displace the brook trout (*Salvelinus fontinalis*) and Atlantic salmon (*Salmo salar*) respectively, from east coast rivers (Gibson, 1978).

In the United States, examples of exotic aquatic species introduction are even more prevalent. The introduction of aquatic plant species, such as the watermilfoil and water hyacinth (*Eichhornia crassipes*), has caused major infestation problems. The grass carp, *Ctenopharyngodon idella*, introduced into the United States to control problem aquatic weeds, has the potential to destroy aquatic vegetation and habitats, and cause an ecological disaster among important native aquatic

organisms (Lackner et. al., 1970). Introduction of the oyster drill, *Urosalpinx cinerea*, (Loosanoff, 1955) and the Asian clam, *Corbicula*, (Lackner et. al., 1970) to new regions in the United States could have extremely expensive consequences.

The accidental transportation of aquatic organisms in or on shipping vessels has been a steady and powerful agent in dispersing foreign organisms throughout the world. The ballast tanks are believed to be a major portable warehouse for the distribution of these organisms. The Chinese mitten crab (*Eriocheir sinensis*) is believed to have been distributed in Europe and North America in this manner. Its first occurrence in North America was reported in Lake Erie in 1973 (Nepszy and Leach, 1973). The European flounder (*Platichthys flesus*), captured in Lake Erie in 1973 and 1976 (Emery and Teleki, 1978), was probably introduced via ballast tanks of ocean-going vessels.

The ballast tanks of foreign shipping vessels have never been thoroughly investigated for their potential to carry viable foreign organisms into the Great Lakes. Therefore, in 1980, a survey of foreign ships' ballast waters was conducted, under a joint Canadian-United States agreement, to determine what exotic organisms are being introduced into the Great Lakes, and their potential for impact, if any, on the Great Lakes' ecosystem.

MATERIALS AND METHODS

SAMPLING

Candidate vessels were sampled at one of two locations: either at the Montreal harbour dock area, or in the St. Lawrence River at the Pointe aux Trembles anchorage site. Any upbound vessel which was carrying at least one full ballast tank was considered to be a potential candidate ship. However, only vessels which had ballasted in the Gulf of St. Lawrence (control vessels) or in 'foreign' waters were actually sampled. Foreign waters were defined as water originating from an area outside of the Great Lakes watershed. Oil tankers which often carry oil as ballast were not considered in the study.

On each candidate vessel, log information pertaining to the physical description of the vessel and the ballast water origin were obtained from the ship's personnel. In an attempt to obtain samples which were representative of the entire water column in a ballast tank, two methods of sampling were conducted. For one-half of the ship's sampled, the aft manhole cover of a double bottom tank was removed to collect a grab sample of ballast water and side-wall encrustations. On the remaining vessels, ballast water was obtained from the discharge side of the ship's water pump which pumped water from the bottom of the tank.

For each water sample, measurements of pH, temperature, salinity and dissolved oxygen were recorded during the sampling

period. Polypropylene containers were used to store all samples of ballast water. One litre of sample was collected and stored on ice for future BOD₅ analysis. For oil and grease analysis, a 3.8 litre sample was collected, preserved with 2ml/l H₂SO₄ to reduce the pH (≤ 2), and stored on ice. Two 1 litre and one 3.8 litre samples were collected and preserved with 5ml/l HNO₃ for cadmium, mercury and lead analysis. As part of the joint Canadian-U.S. agreement, the heavy metal samples were shipped to the U.S. authorities for analysis.

For microbiological analysis, 200ml water samples were collected and stored on ice for the determination of Total Coliform and Enteric (Fecal) Streptococci content. For ballast waters that were known to originate from areas heavily polluted by human wastes, 5.7 litres of sample water were collected and stored on ice for analysis of *Vibrio* spp. and hepatitis virus.

For macrobiological analysis, all organisms which were greater than 80 μ were identified and enumerated. Nannoplankton and smaller organisms were not considered in the study. Up to 100 litres of sample water were passed through a separation tube containing 200 μ and 80 μ nitex screens in series. The residue on the 200 μ screen, which represented almost all zooplankton and larger organisms, was stained with a 1:1 mixture of Eosin B and Biebrick scarlet stains in a 1:1000 concentration of 5% formalin,

and preserved in 10% formalin. The vital stain was intended to provide a measure of the relative number of animal organisms which were alive at the time of sampling. Residue on the 80 μ screen consisted mostly of phytoplankton and was preserved in FAA (Formalin-Acetic Acid-Alcohol). A separate unpreserved water sample was scanned under a compound microscope (400x) at the time of sampling to ascertain if any live animal organisms were present based on any obvious physical activity.

Only one ship ballast tank contained encrustations. These were scraped from the inside walls of the manhole area and preserved in 10% formalin.

ANALYSIS

The chemical analysis for BOD₅, oil and grease, and the heavy metals, cadmium, mercury and lead were conducted according to Standard Methods (APHA, 1976). The microbiological analysis for Total Coliform and Enteric Streptococci were also determined according to Standard Methods (APHA, 1976). Analysis for the presence of *Vibrio* spp. and hepatitis virus used standard public health laboratory protocols.

Identification and enumeration of phytoplankton were adapted from the procedures of Prescott (1970), Stein (1973),

and Stofan and Grant (1978). The procedure was comparable to the technique used by Stoermer et al (1975). Phytoplankton were concentrated into 10ml scintillation vials by passing the sample through a 80 μ nitex screen. The concentrate was allowed to settle for a minimum of 72 hours prior to subsampling. The sample volume was then reduced to 5ml by drawing off the excess liquid using a fine gauge syringe. The integrity of the meniscus was maintained to prevent any phytoplankton trapped by surface tension from being lost. To aid in the identification of phytoplankton, Lugol's solution was added to the sample.

To subsample, the concentrated sample was agitated so that a random distribution of the organisms was obtained. Two samples (0.85ml each) representing 17% each of the total concentrate were removed from the suspension, using a wide mouth syringe, and fixed on glass microscope slides using a commercial mounting medium. The remaining concentration was sealed in the vial and served as an archival sample.

The phytoplankton material was analyzed using an Olympus system compound microscope permitting a full range of magnification (10-1000x) and allowing dark field, phase contrast and oil immersion. Any zooplankton material found in the samples was also analyzed. Seven phytoplankton samples

were also analyzed using the inverted microscope technique of Lund et al (1958). Samples were stained with Lugol's solution and 10ml settling chambers were used to enumerate the organisms.

Prior to identification, zooplankton samples were concentrated to a 20ml volume, by passing the sample through an 80 μ nitex screen and washing the residue onto a petri dish. The entire sample was analyzed under dissecting and compound microscopes. Any plant material found in the samples was also analyzed.

Organisms were identified when possible to the genus and species level. However, some organisms were in 'poor shape' and could be identified only to a higher taxonomic level. For identification purposes, organisms were assumed to have originated from the point of ballast water origin. General and geographically specific keys were used for the identification and are listed in the references. Organisms were recorded as 'live' or dead; the term 'live' meaning only that organisms were morphologically normal and were stained deeply, or in the case of phytoplankton, that chloroplasts were still intact. It did not imply any physiological activity. Unidentifiable organisms were in poor shape and often only partially present.

RESULTS AND DISCUSSION

Vessel and ballast water characteristics are presented in Tables 1 and 2. Based on the source of ballast water, 10 geographic regions were defined:

<u>Region</u>	<u>Ship No.</u>
I Gulf of St. Lawrence (control)	2, 19, 46, 49
II Atlantic Coast - North America	6, 11, 14, 18, 50
III Atlantic Coast - Caribbean	5, 9, 12, 22, 38, 43, 51
IV Atlantic Coast - Portugal, Spain, France	4, 8, 16, 39
V Atlantic Coast - British Isles, Irish Sea	10, 13, 23, 29, 55
VI English Channel and North Sea	1, 15, 20, 24, 25, 26, 30 34, 36, 42, 52, 53
VII Baltic Sea	28, 31, 32, 48
VIII Mediterranean Sea	3, 17, 27, 33, 35, 40, 41 45, 47
IX Adriatic Sea	7, 21, 37, 54
X Black Sea	44

Vessels which could carry potentially important species from a number of other geographic regions did not arrive at the sampling site during the study period. The regions include the following:

Central America

South America

Africa (except for the Mediterranean Sea)

Asia

Australia

WATER QUALITY OF BALLAST WATER

The combinations of pH, oxygen, temperature and salinity values recorded for the ballast waters (Table 2) would not inhibit a broad range of organisms from surviving. Only two water samples (No. 12 and 43) had pH values outside the acceptable range of 6.0 to 8.3 and these samples were only moderately acidic (5.4 and 4.2 respectively). Oxygen levels ranged from 2.2 to 13.4mg/l and temperatures from 5.6 to 35°C. Salinity levels reflected a wide range of freshwater, marine and brackish water conditions (0.0 to 3.5‰), and can be classified as follows (Perkins, 1974):

Freshwater	-	< 0.05‰
Oligohaline	-	0.05 - 0.5‰
Mesohaline	-	0.51 - 1.8‰
Polyhaline	-	1.81 - 3.0‰
Euhaline	-	> 3.0‰

Bio-chemical analyses of the ballast water samples did not indicate any significant levels of oil and grease, or heavy metals (Table 3). Oil and grease concentrations ranged from 2 to 141mg/l. BOD₅ levels for most samples were very low (1.0 to 9.0mg/l); however, two samples (Nos. 1 and 12) had BOD₅ levels of 35 and 670mg/l respectively. The ballast water in the vessel, Lake Aniara (No. 12), originated from La Romana, Dominican Republic, and examination of the water revealed that it contained

human wastes. This was the only vessel containing known sewage material in the ballast waters, although foreign vessels are permitted to use ballast areas as waste holding tanks. It is also possible that the region at La Romana is an outfall zone for municipal wastes and wastewater was taken up into the ship's tanks during normal ballasting.

MICROBIOLOGICAL ANALYSIS

Only 4 ballast water samples had positive results for Fecal Streptococci determination (Table 4). Two samples had low concentrations of one colony per 100ml (Nos. 27 and 28). The other two samples (Nos. 16 and 25) contained 21 and 37 colonies per 100ml. These levels, although permissible, still exceed the desired criteria level of less than one colony per 100ml for public surface water supplies (MOE, 1974).

The maximum Total Coliform count was 4600 per 100ml for the ballast water samples. This value is less than the recommended maximum permissible level of 5000 per 100ml; however, eleven samples exceed the desired maximum level of less than 100 per 100ml (MOE, 1974). The water sample from La Romana, Dominican Republic had an unusually low value of 460 colonies per 100ml for a sample containing sewage wastes.

MACROBIOLOGICAL ANALYSIS

To classify an organism as a nonendemic or a new foreign species to the Great Lakes was sometimes difficult because such a statement would require, for comparison, a complete identification list to the species level of all the aquatic organisms in the Great Lakes. At present, a compilation of annotated checklists of the Great Lakes flora and fauna has not been conducted, although it has been proposed (Gannon and Robertson, 1978). The literature does contain, however, numerous surveys of the Great Lakes in overview or of specific regions. Unfortunately, in many instances, organism taxonomic classification was not carried to the specific or even generic level. In addition, the reports were sometimes restrictive in their classification to only organisms of interest to the specific survey. Studies in the past, which concentrated on phytoplankton often cited only organisms which represented 5% or more of the total phytoplankton biomass. Therefore, in this study, the assumption was made that if an organism, which was identified in a ballast water sample of foreign origin, was not cited in the available literature as being present in the Great Lakes, the particular organism in question represented a potential foreign species.

The results and discussion of the macrobiological survey that follow have been divided into three sections: Aquatic Flora, Aquatic Fauna and Terrestrial Fauna. Organisms within each section were discussed by taxonomic group. The terrestrial fauna found in the study, although not intended as part of the study, have been included for completeness.

1. AQUATIC FLORA

Although all ballast water samples contained plant material, the macrophyte component consisted of fragments which were not sufficiently intact to identify. Of the fifty-five ships sampled, all but six (Nos. 1, 4, 15, 27, 28, 29) contained phytoplankton material in the ballast grab sample. A total of forty-two vessels (76%) were found to have at least one potentially viable algal organism which had survived transport in a ballast tank. Another seven ships (Nos. 11, 12, 30, 34, 47, 51, 54) had phytoplankton present in the ballast waters; however, none appeared morphologically intact.

Of the eleven major phytoplankton divisions (Chapman and Chapman, 1973), only the Chloromonadophyta were absent from the samples. The chloromonads consist of seven species, only one of which is marine. These algae are the least represented in any phytoplankton sample due to their small numbers, size and distribution (Bourelly, 1968; Chapman and Chapman, 1973).

The remaining ten divisions are comprised of fourteen classes, three of which were not represented in the samples (Prasinophyceae, Haptophyceae, and Charophyceae). The Prasinophyceae and Haptophyceae are relatively new, small classes of the green (Chlorophyta) and gold-brown (Chrysophyta) algae respectively. They represent organisms least common to phytoplankton sampling (Bourelly, 1966; Chapman and Chapman, 1973).

The Charophyceae (Chlorophyta), represented by only a few species, are predominately benthic freshwater organisms. Of macroscopic proportions, these plants are usually not part of the phytoplankton community and were, therefore, not expected to be present in the samples.

For discussion, the phytoplankton found in the ballast water samples are grouped by class. A list of the species of phytoplankton identified is presented in Table 5.

1.1 Bacillariophyceae

Diatoms are abundant in both the marine and freshwater plankton communities and also comprise a major component of the benthic flora in lakes and salt marshes. Their salinity tolerances vary with genus and species (Chapman and Chapman, 1973).

The following species which were identified in the samples are not endemic to the Great Lakes:

Belleriochea sp.

Hannaea arcus

Biddulphia spp.

Hydrosera spp.

Campylodiscus spp.

Triceratium spp.

Chaetoceros spp.

Leptocylicindricus danicus

Corethon sp.

Thallasionema sp.

Of these diatoms, *Chaetoceros* has been identified in the St. Lawrence estuary (Sinclair, 1978). The remaining species represent typical marine diatoms common to the British Isles and North Sea (Newell and Newell, 1977). However, many other Bacillariophytes which are common to the North Sea have been found in the St. Lawrence estuary (Round, 1965). Very few diatoms were actually observed in any of the North Sea/English Channel samples which may be attributed in part to the sampling period and phytoplankton community periodicity.

One diatom species, *Biddulphia sinensis*, which is not indigenous to the North Sea, recently was introduced to the region and has since become a major component of the diatom community in parts of the North Sea (Boney, 1966; Elton, 1958). Its introduction is believed to have been via ships' ballast waters originating from Japan. Although this particular species was not identified in the samples examined in this study, its environmental parameter tolerances suggest that it has the potential to become established at least in the St. Lawrence estuary if introduced. The potential impact of this species, if established in Great Lakes waters, cannot be assessed; however, it does represent an example of the potential for the introduction of foreign organisms indigenous to regions not actually sampled.

The occurrence of nonendemic diatoms in ballast waters and their potential to establish themselves in the Great Lakes may be related to their conspecificity and adaptability. Certain freshwater and brackish water diatoms have been found to be conspecific (Hasle and Evensen, 1976). Valve process morphology, influenced by the salinity of the water, has led to taxonomic difficulties. Therefore, diatoms, formally thought to have a narrow salinity tolerance range may actually have very broad salinity tolerances.

The ability of diatoms to adjust to varied environmental conditions is demonstrated by two 'marine' bacillariophytes which have recently been identified in the Great Lakes. *Coscinodiscus rothii* (Taft and Taft, 1971) and *Actinocyclus* sp. (Prescott, 1970) were originally considered strictly marine organisms; however, both organisms have been successfully introduced to Lake Erie in the past 30 years. At present, *C. rothii* is a major component of the Lake Erie biomass (Gladish and Munawar, 1980; Munawar and Burns, 1976; Munawar and Munawar, 1976). It has also been identified at levels >5% of the biomass in Lake Superior (Munawar et al, 1978).

The diatoms in the previous table represent a variety of marine species with diverse salinity tolerances. Many of the diatoms were in a viable condition in the ballast water samples.

Given suitable conditions, it is conceivable that these organisms have the potential to invade and become established in the Great Lakes system. However, further investigation would be necessary to establish actual salinity tolerances and invasive potential.

Only four Bacillariophyceae genera were found in freshwater ballast tank samples: *Fragellaria* sp., *Tabellaria* sp., *Coscinodiscus* sp. and *Melosira* sp. The first three genera were present in the 'control' samples from the Gulf of St. Lawrence and are probably endemic to the Great Lakes. *Melosira* sp. was found in ballast water from the Black Sea region and may represent a new species or variety introduction to the Great Lakes.

All other diatoms were found in mixohaline (0.05-3.0‰ salinity) waters. Those organisms from foreign regions may be diatoms foreign to the Great Lakes and could become established if conditions are suitable.

The marine species of diatoms are not generally recognized as problem organisms in their native habitats. However, a bloom of *Chaetoceros* did occur and resulted in brown algal mats being washed up on shorelines, causing colour, odour and aesthetic problems (Round, 1965). Of the more saline tolerant species, some algae cause problems such as blooms in eutrophic or polluted

estuaries. A list of fresh and brackish water species of biological importance are listed in Table 7.

1.2 Dinophyceae

Ecologically, this group of biflagellated organisms often alternate with the Bacillariophyceae as the significant component of the marine phytoplankton biota (Bold and Wynne, 1978; Perkins, 1974). Common to fresh, brackish and marine waters, the group is best known for their bioluminescent qualities, red tides, and toxin production.

The occurrence of *Ceratium* was high in the samples, reflecting the cosmopolitan nature of the genus. Seventy percent of all vessels containing phytoplankton contained *Ceratium* representatives. However, only *C. hirundinella* (Nos. 2, 7, 18, 46, 49) is a freshwater species and is endemic to the Great Lakes.

The remaining dinoflagellates were marine species which, as a group, are restricted by their salinity tolerances. Their introduction to freshwater is physiologically impossible (Bold and Wynne, 1978).

The following marine species identified in the ballast samples are listed as being present in the St. Lawrence estuary (Sinclair, 1978):

*Ceratium tripos**Peridiniopsis* sp.*Ceratium* spp.*Peridinium* sp.

Dinoflagellate blooms are often correlated to changes in temperature and salinity (Perkins, 1974). Red tide blooms are also influenced by rainfall and runoff, their maximum population growth occurring immediately after heavy rainfalls (Bold and Wynne, 1978; Perkins, 1974). Red tide may pose a potential problem as an incoming species because they produce toxins. Although it is unlikely that any marine dinoflagellates could establish themselves in the Great Lakes, a large population in ballast tank water could, if dumped, cause a temporary localized problem. The species *Gymnodium veneficum*, *G. brevis* and *Gonyaulox monilata* are all known to have caused fish kills in marine waters (Gorham, 1964). *Gonyaulox catenalla* and *G. tamarensis* can be accumulated by shellfish (Gorham, 1964) and cause paralytic shellfish poisoning in humans. *Gonyaulox polyedra* and *Ceratium furca* (Nos. 18 and 35) are also known to produce red tides when salinities are low and temperatures high (Perkins, 1974). In all instances, nutrient levels must also be high (Bold and Wynne, 1978; Perkins, 1974).

Other problems can occur with the introduction of dinoflagellates. *Gonyaulox polyedra* was found to concentrate radio-nucleotides at a nuclear test site up to 7000 times the ambient

level (North et al, 1972). Other dinoflagellates are known parasites of fish and invertebrates (Chapman and Chapman, 1973); however, these are marine species and have little potential for impact in the Great Lakes. Other biologically important Dinophytes are listed in Table 8.

1.3 Desmophyceae

This is a very small class of flagellates, similar to the dinoflagellates, and known as the Desmoks. Only two genera were identified in the ballast samples: *Phalacroma* in ship number 37, and *Procentrum* in ships number 7 and 25. Although the organisms probably represent marine species, *Procentrum* has both fresh and brackish water representatives. The marine species have the same salinity tolerance restrictions as the Dinophyceae; and therefore, pose little threat as an introduced species to the Great Lakes.

Procentrum may form a major component of the marine biota (Perkins, 1974) and may also be common in polluted estuarine areas (Palmer, 1977). Chapman (1973) also classified *Procentrum* as contributing to red tides. Its potential impact is therefore similar to the red tide species of the Dinophyceae.

Little information is known of *Phalacroma*, except that it represents a major component in some marine phytoplankton communities (Round, 1965).

1.4 Chlorophyceae

The green algae, characterized by their pigment composition and starch storage (Bold and Wynne, 1978), are the most diverse group of algae morphologically, physiologically and ecologically. There are over 7000 species that are common in both the benthic and planktonic flora (Chapman and Chapman, 1973). Species morphological plasticity can occur in some organisms according to environmental conditions, and some have the ability to produce interspecific hybrids.

The freshwater species are cosmopolitan in distribution, whereas the marine species are generally restricted to distinct geographic regions. However, successful introduction of marine forms to new areas has occurred (Boney, 1966; Chapman and Chapman, 1973; Round, 1965). No marine species were found in the ballast water samples.

Because of the ecological diversity and size of this class, the discussion of the organisms that follows has been divided into the seven orders represented in the ballast water samples.

1.4.1 Chaetophorales

The branched filaments of this group are usually found attached in quiescent freshwater areas. None form a major component of the Great Lakes phytoplankton biomass.

Cladophora spp., *Chaetophora* spp. and *Stigeoclonium* spp. occur in Lake Erie (Taft and Taft, 1971); *Chaetonemopsis* sp. was found in a sample from the St. Lawrence estuary (No. 19); and, *Microthamnion strictissimum* and *Ctenocladus* sp. were found in Atlantic Coast (North America) samples (Nos. 18 and 50). All these species are common to the Western Great Lakes area (Prescott, 1970; Smith, 1950); therefore, it is unlikely that any of these organisms represent a foreign species. However, *Chaetophora* was also found in a sample originating in the Mediterranean Sea (No. 40) and may represent a species distinct from those found in the Great Lakes.

Chaetophora and *Stigeoclonium* are the most common problem organisms of the Chaetophorales. *Chaetophora* is generally associated with algal covering problems, while *Stigeoclonium* is common in sewage ponds. *Stigeoclonium tenuis* also occurs in areas of freshwater pollution (Palmer, 1977).

A characteristic trait of the family, Chaetophoraceae, may be ecologically important. Many Chaetophoraceae, especially *Chaetophora*, have a mucous coating covering the filaments. The coating is capable of carrying aquatic species of fungi, as was demonstrated for *Stigeoclonium* by Islam (1963). The introduction of foreign myxomycetes is therefore possible when nonedemic Chaetophoraceae are transferred into the Great Lakes.

1.4.2 Chlorococcales

Members of this order are unicellular or colonial, non-motile green algae. All the identified Chlorococcales in the ballast samples except *Scenedesmus crassus* are known to be endemic in the Great Lakes (Taft and Taft, 1971). However, since other species of *Scenedesmus* are endemic to the Great Lakes and *S. crassus* was found in a sample (No. 18) originating from the Atlantic Coast (North America), it probably is an endemic species.

Many of the identified species were also found in samples from foreign waters. Since many varieties of the species are known to exist, especially in the family, Hydrodictyaceae, these organisms may represent foreign organisms. They include:

Ankistrodesmus faleatus

Elaktothrix sp.

Pediastrum boryanum

P. duplex

P. simplex

P. spp.

Scenedesmus and *Pediastrum* both secrete toxins which can be autoantagonistic and heteroantagonistic (Lefèvre, 1964). Therefore, the introduction of a new species of these genera may also introduce new toxin secretions.

A human health related problem is associated with the genus, *Chlorococcum*. Species of this genus are believed to have invaded lesions in humans with mycoses (De Almeida et al, 1946). However, the exact relationship of the algae to the disease is not known.

A list of some of the more biologically important organism of this class, found in the samples, and their potential impact is presented in Table 9 .

1.4.3 Cladophorales

The algae in this order are branched or non-branched, attached and filamentous, and are represented in all three habitats: freshwater, brackish and marine. Of the four most common genera, *Cladophora* and *Rhizoclonium* are found in all three habitats; while *Pithophora* is restricted to freshwater and *Chaetomorpha* to marine waters (Bold and Wynne, 1978).

Only *Cladophora* was present in the ballast samples (Nos. 18, 40, 49, 50, 52). It is endemic to the Great Lakes (Taft and Taft, 1971). However, many species exist and some European species, such as those found in the Mediterranean Sea (No. 40) and in the English Channel and North Sea (No. 52), may be distinct species from those in the Great Lakes (Van den Hoek, 1963).

Marine forms of *Cladophora* are associated with ship fouling, and are also known to form large rolling algal mats in open water (Boney, 1966). Palmer (1977) noted a number of freshwater pollution related problems for this genus. Blooms are common in eutrophic waters and sewage ponds. *Cladophora algagrophila* blooms cause filter clogging, while *C. glomerata* and *C. insignis* contribute to water colour and taste problems. *Cladophora glomerata* is tolerant of heavy metal pollution and has been proposed for use as a potential biological monitor (Keeney et al 1976). These species are probably endemic to the Great Lakes. *Cladophora* appears very adaptable to its environment, and foreign species introductions may result in the establishment of additional problem organisms.

1.4.4 Ulvaes

The Ulvaes are almost exclusively marine organisms; however, a few (*Schizomeris* and *Trichosarcina*) are freshwater obligotrophs (Bold and Wynne, 1978). Some marine genera, *Enteromorpha* and *Monostroma* have demonstrated an ability to adapt, in an altered morphological state, to the reduced salinities of inland waters. They now inhabit cold mountain streams in the United States (Prescott, 1970).

Schizomeris leibleinii, the only species of the Ulvaes found in the ballast waters, occurred in a St. Lawrence estuary

sample and is probably endemic to the Great Lakes. The species is common around drain entrances and in the effluents of sewage treatment plants (Palmer, 1977).

Little information is known of the potential impact of invading species of Ulvales and, at present, the order is not considered to be a major environmental problem.

1.4.5 Ulotrichales

This class is composed of three families of filamentous, non-branched, uninucleate, green algae: Microsporaceae, Cylindrocapsaceae, and Ulotrichaceae. The first two families are exclusively freshwater, while the Ulotrichaceae occurs in both marine water and freshwater (Chapman and Chapman, 1973).

Microspora is the only genus of the family Microsporaceae and was found in a St. Lawrence estuary sample (No. 46). It is probably endemic to the Great Lakes.

Cylindrocapsa is the only genus of the family Cylindrocapsaceae. Although not found in the ballast samples, it is endemic to the Great Lakes (Taft and Taft, 1971).

All the genera of the Ulotrichaceae found in the ballast samples are endemic to the Great Lakes (Taft and Taft, 1971).

Ulothrix occurred in both marine and freshwater samples. The marine species are copper tolerant and contribute to ship fouling (Boney, 1966). *Binuclearia* and *Geminella*, which are obligate freshwater organisms, were identified in a sample from the Caribbean Sea (No. 9), which had a salinity of 2.1‰. Therefore, the sample was probably a mixture of marine and fresh waters.

Although the genera mentioned for this class are endemic to the Great Lakes, the species being introduced from foreign vessels are probably not endemic. Some of the more biologically important species of this class and their potential impact are presented in Table 10.

1.4.6 Volvocales

This order is composed of unicellular and coenobic organisms which are normally motile via flagella. Species are found in all aquatic environments and may produce zygotes and akinetes, thereby persisting in adverse environmental conditions.

The species are generally too small to have been caught by the 80 μ mesh screen sampling apparatus. The single genus identified was *Pteromonas*. Only the lorica was found with a minimum of cytoplasmic material.

There are a number of species of biological importance belonging to this class. Although not found in the samples, their significance is listed in Table 11.

1.4.7 Zygnematales

This order is composed of three distinct families: the Zygnemataceae - filamentous, unbranched green algae; the Desmidiaceae - placoderm desmids; and, the Mesotaeniaceae - saccoderm desmids. Only the first two families were represented in the ballast samples. All members of the order are exclusively freshwater algae.

The Zygnemataceae has 580 freshwater species. Five genera of this family were identified in the ballast samples and are endemic to the Great Lakes (Taft and Taft, 1971). However, not all organisms originated from North America waters (e.g. *Mougeotia* spp. from the Caribbean, North and Mediterranean Seas regions; and, *Spirogyra* spp. from the North Sea region). These organisms could represent new species introductions.

The Desmidiaceae are an extremely widespread family with individual species favouring soft, acidic waters (Chapman and Chapman, 1973; Round, 1965). Their most predominant period

in the biomass is late spring and early summer. Only two genera of this family were found in the ballast samples, which probably reflects the time of year of sampling and the limited number of freshwater ballast samples collected. A few species of the genus *Staurastrum* are endemic to the Great Lakes (Tarapchak et al, 1976). *Hyalotheca* sp. and *Staurastrum sebaldi* are both present in Lake Erie (Taft and Taft, 1971). *Staurastrum sebaldi* was also found in a Mediterranean Sea sample (No. 40). *Staurastrum* spp. were recorded in a number of foreign water samples (Nos. 7, 16, 37, 42, 43). Most were dead upon arrival. However, they may represent new species introductions to the Great Lakes.

Within clones of identical species of the Desmidiaceae, cytological work has indicated that large variations can occur (Chapman and Chapman, 1973). Whether this affects speciation and adaptability is not known; and, therefore, it is difficult to estimate the potential impact of importation for this group.

The Desmidiaceae are known to affect water colour and taste. In combination with filamentous blue-green algae, they tend to unite the filaments and augment the filter-clogging nature of the cyanophytes.

Many species of the class Zygnematales affect water quality. Some of these and their significance are listed in Table 12.

1.4.8 Other Orders of Chlorophyceae

A group which was not identified in the ballast samples was the parasitic Chlorophyceae. Genera such as *Entocladia*, *Chlorochytrium*, *Cephaleuros* and *Polysiphon* all have representative parasitic forms. Of these, only an endophytic species of *Chlorochytrium* is endemic to Lake Erie (Taft and Taft, 1971).

Also, no representatives of the major marine orders of Chlorophyceae were encountered in the samples. These organisms are attached, benthic forms which rarely enter the water column. The group is generally restricted to saline, sessile, habitats. However, the introduction of other marine forms and conspecific marine forms to the Great Lakes has been previously discussed. Therefore, there is the possibility that these benthic forms can be introduced.

1.5 Euglenophyceae

This class is widely distributed but almost exclusively freshwater (Chapman and Chapman, 1973). They are heterotrophic and blooms are predominant in stagnant ponds or tanks.

Although this group was expected to be represented in the ballast samples, only *Euglena* spp. were found in 4 samples (Nos. 7, 18, 35, 48), and in two (Nos. 7 and 48), the species were not viable. *Euglena* is endemic in the Great Lakes (Taft and Taft, 1971).

Time of year of sampling or habitat preference may be factors influencing the occurrence of low numbers of this group. Also, if conditions were unfavourable in the ballast tanks, these organisms may have encysted and fallen to the base of the tanks.

Like desmids, euglenoids are often associated with filamentous blooms (Round, 1965). They tend to bind the algal strands and enhance the capacity of the bloom to act as a covering or clogging agent.

The salinity tolerances of this group are not well known and it is difficult to evaluate the degree to which importation and subsequent introduction to the Great Lakes can occur. Ecologically, the euglenoids often are a major part of the food chain; therefore, introduced new species may have a potential impact to the ecosystem.

The biological significance of some euglenoids have been recorded by Palmer (1977) and are listed in Table 13.

1.6 Xanthophyceae

Members of the yellow-green algae are represented by a variety of forms and occur in all habitats: marine, brackish

and freshwater. Like the euglenoids, this group has approximately 450 species, only 15% of which are marine (Chapman and Chapman, 1973).

The Tribonematales, of which three species were found in the samples, are exclusively freshwater. All are endemic at least to Lake Erie (Taft and Taft, 1971). *Tribonema* is associated with eutrophication and filter clogging problems. The species from the North and the Caribbean Seas may be foreign species, and therefore, represent a new introduction to the Great Lakes.

Botrydiopsis sp. is a cosmopolitan species (Bourelly, 1968), and although it was found in an Atlantic coast sample, it is probably endemic to the Great Lakes.

Like many of the smaller classes of phytoplankton, very little is known of Xanthophyte species tolerances to salinity, temperature, or habitat. Therefore, to speculate on its potential for impact on the Great Lakes ecosystem would be difficult.

1.7 Chrysophyceae

Most species of the gold-brown algae are unicellular; however, there are a few colonial forms and a very few filamentous forms (Chapman and Chapman, 1973). Approximately 20% of

the species in this class are marine with a few families being exclusively marine. Some species have representatives in both freshwater and marine mediums. They generally prefer unpolluted zones in cold or temperate waters. Conspecificity may occur in this class as it does in the Bacillariophyceae and Chlorophyceae.

A high number of organisms belonging to the Chrysophyceae were found in the ballast samples. However, this class is a principal component of the nanoplankton ($<80\mu$) which were not sampled in the study. The few organisms which were sampled were unidentifiable flagellates.

Although this class was not in the study, there are some biologically important species which primarily affect water colour and taste. They have been listed in Table 14.

1.8 Cryptophyceae

The cryptomonads are nanoplanktonic unicellular flagellates of approximately 100 species. They occur in both freshwater and marine environments and some species are euryhaline (Huber-Pestalozzi, 1950; Butcher, 1967).

Although the nanoplankton were not sampled in the study, a few in this class were identifiable. All belonged to the

order Cryptomonadales and are probably euryhaline species:

Chroomonas spp.

Rhodomonas sp.

Cryptomonas spp.

The three genera are endemic to the Great Lakes, but the species may be foreign. The genera are problem organisms and their biological significances are listed in Table 15.

1.9 Cyanophyceae

It is estimated that there are as many as 7500 species of blue-green algae occurring in both freshwater and marine habitats. The cyanophytes occupy benthic, epipellic and planktonic stratas and are characterized by their lack of a distinct nucleus or chloroplast.

The following species identified in the samples are probably not endemic to the Great Lakes:

Agmenellum thermale

Anabaena oscillaroides

Anacystis aeruginosa

A. marina

A. montana

Aphanocapsa rivularis

Microcystis viridis

Oscillatoria lutea

Spiralina subsala

The genus, *Aphanocapsa*, however, represents a major component of the Great Lakes phytoplankton biomass (Munawar et al, 1978).

Of the above species, only *Aphanocapsa rivularis* is a known obligate freshwater species. It was present in the St. Lawrence estuary and has been recorded in the lakes of Michigan (Prescott, 1970); however, it has not occurred in the Great Lakes.

Table 16 illustrates the cosmopolitan nature and universal distribution of this class. If the above species are indeed foreign, their adaptability should allow them to survive in the Great Lakes.

Almost all blue-green algae are both eurythermal and euryhaline (Humm and Wicks, 1980). Many species are also known to display environmentally induced morphological variations (e.g. *Nostoc* and *Lyngbya*). Of all the algae, the blue-greens are the most recognized problem group. They cause clogging, fouling, fish kills; are associated with taste and odour problems; and, occur as various toxic blooms. *Lyngbya majuscula* has caused dermatitis in man (Moikeha et al, 1971; Moikeha and Chu, 1971). *Oscillatoria rubescens*, common in Great Lakes phytoplankton samples, has been found blooming under the ice in Scandanavia, polluting local water supplies (Skulsberg, 1962). *Oscillatoria erythraea* causes the red appearance of the Red Sea

and has been linked to fish kills (Humm and Wicks, 1980). Blue-greens, such as *Microcystis*, *Spirulina* and *Anabaena*, are not only known to produce toxins harmful to both man and animal, but also secrete heteroantagonistic toxins, affecting other members of the phytoplankton community (Gorham, 1964; Lefèvre, 1964; Schwimmer and Schwimmer, 1964).

A synopsis of problem and potential problem organisms belonging to this group is beyond the scope of this report. However, the biological significance of some of the species encountered in the ballast samples are listed in Table 17.

In addition to the direct environmental impact that many blue-green algae have, recent studies (Safferman and Morris, 1963; Smith et al, 1966 a, b, 1967) have indicated the presence of a phycovirus that attacks blue-green algae. The disruptive nature of this cyanophage on indigenous blue-green populations has already been demonstrated (Safferman, 1973). If infected populations are taken up in ballast waters, it is possible for the virus to be transported and introduced to native species. Such an introduction could cause massive upsets in the seasonal and regional ecology of the Great Lakes.

1.10 Rhodophyceae

The red algae are primarily benthic littoral plants of the marine environment. There are approximately 4000 known

species of which only 200 are freshwater organisms (Chapman and Chapman, 1973). The majority of marine species are macrophytic; while freshwater genera are usually much smaller and are commonly found in cold, fast-flowing waters.

Only *Rhodocorton* (*Audouinella*) was found in the ballast samples. Two of the samples were from the St. Lawrence estuary; and, although *Rhodocorton* is not known to be endemic to the Great Lakes, it probably does occur. *Audouinella violacea* may be the most widespread freshwater red algae in North America (Flint, 1970). It was identified in Quebec streams in 1957 (Flint, 1957) and was recently found in Ontario streams (Sheath and Hynes, 1980).

Rhodocorton was also identified in a polyhaline sample from the American Atlantic coast. Since there are both marine (Bold and Wynne, 1978) and freshwater (Prescott, 1970; Sheath and Hynes, 1980) species of this genus, it is possible that the algae is not endemic to the Great Lakes.

The occurrence of red algae in Canadian waters has become a major environmental concern in recent years. In 1980, Sheath and Hynes recorded eight new taxa of Rhodophyta in Ontario streams.

In the early 1940's, the appearance of *Bangia atropurpurea* was identified in the tributaries of the Great Lakes (Taft, 1970). It was later identified in western Lake Erie in 1966 (Taft, 1970), in Lake Michigan (Lin and Blum, 1977), and Lake Ontario in 1958 (Damann, 1979), and in Lake Huron in 1975 (Lin and Blum, 1977). Lin and Blum (1977) and Taft (1970) proposed that vessels moving from the St. Lawrence Seaway into the Great Lakes may have promoted the transfer of the organism. Recent studies (Reed, 1980; Sheath and Cole, 1980; Yarish et al, 1980) have verified that this species can adapt immediately from saline to freshwater conditions. Sheath and Blum (1980) examined the distribution of the species in the Great Lakes and found the patterns supported the hypothesis that the species was migrating from the seaway inland. Originally, two species were described for this situation: *B. fuscopurpurea* was considered the marine form and *B. atropurpurea*, the freshwater form. Recent studies (Geesink, 1973; Sheath and Cole, 1980) indicate that the two species are actually one and that the situation occurring in the Great Lakes was an invasion by a marine species. Conspecificity of the two forms was confirmed by Reed (1980) who found that *B. atropurpurea* was a well adapted ecotype of the marine form.

Bangia fuscopurpurea is very tolerant of organic pollution (Grenager, 1957) and blooms of the species cause fouling

and clogging problems (Boney, 1951). *B. atropurpurea* has established a definite niche along the shoreline zones of the Great Lakes (Sheath and Cole, 1980).

The identification of *Bangia atropurpurea* in the Great Lakes-St. Lawrence system is a definitive example of a non-endemic marine species invasion into freshwater, and indicates the vital role that ballast water transportation can play. Other potential invaders may also be present in the Rhodophyta. Bold and Wynne (1978) and Yarisich et al (1980) list a number of species with a wide tolerance range.

1.11 Phaeophyceae

The brown algae have approximately 1500 species, most of which are marine. Only five genera are recognized in freshwater. Although the majority of species are macroscopic, there are some forms found as microscopic thalli.

Two members of the class were found in the ballast water samples: *Ectocarpus* sp. and an unidentified species. Ectocarpaceae are widely distributed in the marine environment.

Invasion into freshwaters or estuaries by marine species of this class is unlikely. Species are not known for wide

temperature, salinity and dessication tolerances; and therefore, are not physiologically adapted to tolerate a wide range of environmental stress (Round, 1965; Grenager, 1957).

Incoming ballast waters should, however, be monitored for the presence of freshwater species of Phaeophytes. No species of this class are recorded as being present in the Great Lakes (Taft and Taft, 1971).

2. AQUATIC FAUNA

Zooplankton made up the majority of animal organisms found in the ship ballast samples. These included animals which are planktonic through their entire life cycle and those which are planktonic for at least one stage in their development. In several samples, benthic forms were also included as well as a few terrestrial specimens. Of the 55 ships sampled, all but three (Nos. 4, 45, 51) contained some form of aquatic invertebrate fauna in the ballast grab sample. A total of 49 ships (89%) were found to have at least one viable invertebrate form. The remaining three vessels (Nos. 9, 12, 13) contained some invertebrates which were, however, non-viable.

The taxa covered a broad range of complexity, from Protozoa to Deuterostomes, with representatives from most of the major zooplankton groups (Table 18).

2.1 Protozoa

Apart from a few unidentifiable, incomplete ciliate forms, all of the zoo-protozoans present were identified as free-living marine forms of Tintinnida (Davis, 1954), which are not endemic to the Great Lakes (Watson, 1974; Leach, 1973). Four genera of Tintinnida: *Strambidinopsis*, *Tintinnidium*,

Tintinnopsis and *Codonella* have species currently endemic to the Great Lakes (Leach, 1973); however, their marine species are restricted to salinities greater than 0.3‰, effectively restricting them to estuarine areas (Green, 1975). The introduction of a nonindigenous species would be difficult to assess as Tintinnids are not known to be problem organisms. Marine protozoans are unlikely to survive when introduced from a ballast tank into the Great Lakes. Very few protozoans are capable of moving directly from marine to fresh water without a gradual acclimation to the change in salinity (Pennak, 1978).

Most forms of protozoa are free-living species and are of little known significance apart from their importance in completing an intrinsic part of the food chain, the holozoic species forming an essential link between particulate living and dead material (Pennak, 1978). Where these free-living forms do achieve some noticeable impact is in municipal water supplies from rivers, lakes and reservoirs during the summer. At this time, blooms of *Ceratium*, *Peridinium* and other dinoflagellate forms can cause severely disagreeable odours and taste, particularly in eutrophic waters. These species were discussed in the phytoplankton sections of the report.

The parasitic forms of protozoa are of particular importance for their impact on human health and economic conditions.

One species of the order Amoebida is *Entamoeba histolytica*, an amoeboid parasite, which is normally restricted to the tropics or sub-tropics (Meglitsch, 1972) and is responsible for dysentery in man and other mammals. Another parasitic group - Subphylum Sporozoa - consists entirely of parasitic forms. The coccidian species include those which infect the intestinal or blood cells, cause human malaria (*Plasmodium*) and the coccidiosis of domesticated animals (Barnes, 1968). Transmittal of these parasites is particularly enhanced by the formation of cysts and spores which are capable of surviving an extreme change of conditions (Pennak, 1978; Meglitsch, 1972; Barnes, 1968). These cysts are released in feces of the infected host and are then ingested by the new host from infected food and water. In the case of malaria, a host mosquito, *Anopheles quadrimaculatus*, is currently indigenous to the Great Lakes area (Wood, 1979), so the possibility of malaria becoming a problem definitely exists. The sampling methods used in the study were not likely to have revealed the presence of these cysts, since they would be at the bottom of the ballast tanks. Their most likely sources are ports from the South American, Mediterranean, Near East and Oriental regions, particularly in eutrophic waters and ports contaminated with untreated waste (Meglitsch, 1972; Barnes, 1968). Their survival would depend upon their chances of being placed in a suitably warm environment, such as a thermal effluent, which

would closely match their natural habitat. It is unlikely that these tropical organisms could tolerate the low temperature regions of the Great Lakes in general.

2.2 Rotifera

Rotifers form a major part of the freshwater food chain, second only to the Cladocera, appearing as herbivorous and predacious species (Davis, 1955). They are predominantly freshwater organisms with some genera also present in the marine environment. Only 2 genera (*Seison* and *Zelinkiella*) are known to be restricted to marine habitats. Some freshwater forms have successfully become established in brackish waters (ie. *Synchaeta*) (Pennak, 1978).

All of the identifiable rotifers found in the ballast water samples belonged to the single genus *Keratella*. Those identified as *K. quadrata* are indigenous to the Great Lakes (Davis, 1966; Watson, 1974.) The remaining *Keratella* sp. largely originated from waters with salinities greater than 1.8‰ (Nos. 20, 23, 42, 55) which indicates a brackish marine species. One such species which has been found in waters with salinities greater than 0.2‰ is *Keratella eichwaldi*, which is currently not recorded from the Great Lakes (Watson, 1974). For the most part, Rotifers are generally regarded as cosmopolitan with few exceptions. It has been stated that if a body of freshwater is capable of sustaining a particular rotifer, it is probably already there.

This situation is attributed to the organisms' ability to form resistant resting eggs which can withstand broad ranges of adverse environmental conditions and which can be easily transported by wind and animals (Pennak, 1978). Since rotifers, in general, are not described as problem organisms, the impact of a new species introduction would be expressed through its competitive abilities. A significant detrimental impact is unlikely.

2.3 Nematoda

Nematodes are one of the most ubiquitous groups present in almost every environment in a broad variety of adaptations from free-living to parasitic, often within the life cycle of a single species (Meglitsch, 1972; Chitwood, 1974). Four of the ships (Nos. 1, 7, 16, 33) carrying nematodes were probably carrying marine species which would not be able to survive in freshwater. While salinity tolerances of nematodes are not well known, few genera occur in both salt and freshwater and fewer still can tolerate a broad salinity change without acclimation (Perkins, 1974). Specimens from ships 2, 6, 37 and 40 were probably brackish forms (salinity $\leq 1.1\%$), of which many are capable of surviving decreased salinities (Meglitsch, 1972; Perkins, 1974).

Due to taxonomic limitations, the specimens were not identified. It may be assumed, however, that the nematodes were free-living forms as these constitute the majority of nematode

species (Chipwood, 1974; Pennak, 1978). Also, none of the nematodes was found to be associated with a host organism. Current knowledge of aquatic free-living forms is relatively limited. Most aquatic genera and many species are cosmopolitan and worldwide, based on scanty distributional records (Pennak, 1978; Chipwood, 1974). Most of the current knowledge is based on the parasitic species due to their enormous impact on man, animals and plants. It is estimated that over 150 million dollars a year is lost in the U.S.A. agricultural sector due to plant nematode parasites (Chipwood, 1974). However, plant nematodes are a terrestrial variety and only occur in the water through runoff. Some of the well-known nematode diseases in man and domestic animal include Dracontiasis, Filariasis, Elephantiasis and Onchocerciasis, all of which are either insignificant or unknown in North America (Chipwood, 1974). Dracontiasis is a tropical to near-tropical disease induced by the nematode *Dracunculus medinensis*. This particular nematode requires a specific species of *Cyclops* (Copepoda-Cyclopoida) prior to its final host (man and animals) in which to develop. Some of these *Cyclops* species associated with *Dracunculus* are *Cyclops bicuspidatus*, *C. vernalis*, *Nemacyclops leukarti* and *Macrocyclus fuscus* (Levine, 1968) all of which are currently indigenous to the Great Lakes (Watson, 1974, 1976). Filariasis, which is caused by *Wucheria bancrofti*, requires a suitable mosquito host for its development and one common

Southern Ontario species, *Culex pipiens* is such a host. The nematode enters the human host during or after the mosquito has its blood meal, entering through the pores or the wound left by the insect (Chipwood, 1974; Levine, 1968).

The potential for the introduction of parasitic nematode species into North American waters is extremely high, based upon present knowledge of nematode abilities to endure broad ranges of environmental factors, adaptability and distribution. Many genera are known to be cosmopolitan and the eggs of parasitic forms are highly resistant to dessication (up to 20 years). Consequently, they are easily transported. Any attempt to determine the possible species which could be introduced is beyond the scope of this report and species identification would require a specialist.

2.4 Mollusca

Both the Gastropod and Pelecypod molluscs were present only as immature planktonic forms (Gastropod-veliger larvae; Pelecypoda-immature adult) which could not be identified due to the poor development of characteristic features. The specimens appeared superficially identical from all the ballast samples they were located in; however, the salinities ranged from 0.75 to 3.6‰ which renders the similarity unlikely.

Mollusc forms represent some of the most invasive and potentially detrimental species recorded as invaders throughout the literature. In fact, three historical introductions into the Great Lakes resulting in the displacement of native species involved molluscs (Cook and Johnson, 1974). These consisted of a northern European snail, *Bithinia tentaculata*; a Japanese snail, *Viviparus malleatus*; and a Chinese freshwater snail, *Cipangopaludina sinensis*. *Bithinia* was originally imported into the Great Lakes by ship in the late 1870's (Cook and Johnson, 1974). It is an extremely predatory and invasive form which is now the most common snail in the northern portion of Lake Ontario and its tributary rivers and streams where it has displaced most of the native species. In addition, *Bithinia* also exhibits a high tolerance to most forms of pollution (Kallas, 1981), a characteristic which gives this species a decided competitive edge. *Viviparus malleatus* is a Japanese form also imported in the late 1870's and it has exhibited displacement of native species to some degree (Cook and Johnson, 1974). The third form, *Cipangopaludina sinensis* is a freshwater snail imported from China for culinary purposes. It has since become established in the Great Lakes and presents a health hazard when lake dwelling specimens are eaten. *Cipangopaludina* concentrates hydrocarbons to levels higher than that in soils, which has led to known cases of carcinogenic poisoning in Montreal and other centres (Kallas, 1981).

A freshwater pelecypod currently causing problems in Europe and Britain is *Dreissenia polymorphus*, a genus currently nonendemic to the Great Lakes. This bivalve mollusc is a recent immigrant from the sea and has retained its veliger larva stage (immature form, unique to marine species) and a byssal (adhesive apparatus) in adult stages. These features have allowed *Dreissinia* to adapt to an epifaunal existence and to colonize stoney areas and regions of fast-flowing freshwater. In Britan and Russia, it is reported to cause the blockage of underground pipes, ducts and channels in reservoir systems and, consequently, retard water flow when it achieves high population levels. With its obvious competitive advantages, it is not surprising to find that where *Dreissenia* occurs, natural populations are displaced (Morton, 1969). In some ports of Europe, it still occurs in estuarine conditions. This situation, coupled with the occurrence of its veliger larvae in the plankton for up to 3 months (Morton, 1969), greatly enhances its potential for introduction to the Great Lakes in ship ballast water. If introduced, *Dreissenia* could establish itself in North America (Kallas, 1981).

2.5 Annelida

Only larval forms of the marine Polychaeta family Spionidae were collected. These included specimens of *Polydora* spp., a genus which has several species represented in the St. Lawrence

estuary (Shih, 1971). All of these are boring species, which attack mussels reducing their market value and burrow into rods and foundations, causing property damage through erosion (Perkins, 1974). *Polydora* appears to be restricted by low salinity levels, however, becoming immobilized in freshwater (Green 1975). This effectively excludes it from the Great Lakes.

There are very few freshwater polychaetes known. Only one, *Manayunkia speciosa* has been recorded in the Great Lakes (Pennak, 1978). Some brackish polychaetes of the genus, *Nereis* are capable of tolerating freshwater as adults using a system of active osmoregulation. However, they cannot establish a reproducing population because immature stages are unable to withstand low salinity levels (Green, 1975; Pennak, 1978). *Nereis limnicola* is an exception, having adopted a viviparous reproductive strategy overcoming this problem.

The other annelid forms found in the ballast water samples belonged to the Oligochaeta, a predominantly freshwater group with very few marine representatives. Both of the specimens found were very small and due to their disrupted condition, only one could be identified down to the family level. This individual belonged to the family Naididae,

which consists of primarily freshwater species, although a few are salinity tolerant (Green, 1975). The Naids are represented in the Great Lakes.

Oligochaetes in general are indicative of pollution levels, with one cosmopolitan species, *Tubifex tubifex*, used as an indicator of organic pollution. They are an important component of the benthic fauna, serving a similar role to that of their terrestrial counterparts in mixing and digesting the bottom muds (Pennak, 1978).

The impact of any new species of oligochaete would be difficult to determine. A detrimental introduction may occur when the nonindigenous species is able to outcompete and replace native oligochaete populations. If the new inhabitant was not as efficient in performing its role of sediment processing as the original forms, then the overall system would suffer.

2.6 Tardigrada

The condition of the tardigrade specimen did not permit further identification. Few of the species are marine, a few are freshwater and the majority are semiaquatic, living on mosses and lichens. North American species, which our specimen

probably is (Ship No. 18), are poorly known, with only 18 freshwater species being recorded as compared to the 40 to 50 species reported from Europe. These 18 species are probably an underestimate, reflecting the lack of widespread sampling programs to enumerate them. However, the potential for introducing a foreign tardigrade from Europe would appear to be good, especially since they are capable of encysting during unfavourable conditions, including dessication, and reemerging in a suitable environment. Their impact would be difficult to assess due to the general lack of information of their ecology in North America and since they are not regarded as problem organisms. Marine or brackish species may also be capable of introduction since tardigrades are apparently able to tolerate salinity differences remarkably well (Meglitsch, 1972; Pennak, 1978; Barnes, 1968; Ward and Whipple, 1959).

2.7 Acarina

The only Acarina found in the ballast water samples was a member of the marine family Halacaridae, which could not be identified further due to its small size and condition on the prepared slide. This family has many forms: herbivores, predators, and a few are parasitic (Davis, 1955). Though largely restricted to the marine environment, several genera are found in freshwaters. Their distributional records are

very poorly developed for the North American regions so the potential of introduction is impossible to discern. Two genera, *Halacarus* and *Copidognathus* are in transition between fresh and salt waters and are found in wells and springs near marine shores (Pennak, 1978).

Until the distributional records of the Halocaridae are developed, it is impractical to assess incoming forms. In addition, their ecology is not well known (Gosner, 1971; Pennak, 1978), so that even foreign species could not be assessed as to their impact. This is an area requiring considerable development.

The other Acarina family, though not found, are the freshwater mites or Hydracarina which are mainly carnivorous or parasitic. Parasitic species are known to attack insect nymphs and mussels. Those which attack mussels do not appear to damage the host, suggesting more of a commensal association (Pennak, 1978).

In general, the distribution of the Hydracarina is not well known, although it appears that most of the species found in North America are restricted to this continent. The genera are more widespread and Pennak (1978) indicates that about half of the genera occurring in the United States have one

species which is widely distributed and common in both North America and Europe. Consequently, the potential introduction of a new species would be difficult to assess for this group, until the distributional accounts are better developed. Hydracarina are not likely to survive a trip of any length, however. The free-living forms are only active during daylight and are immobilized in darkness, resulting in starvation. The eggs could survive as they will remain in this state for up to six weeks if the temperatures and oxygen levels are suitable for the particular species (Pennak, 1978). Hydracarina are not considered to be problem organisms. Therefore, their impact would probably be competition with native species.

2.8 Cladocera

Cladocera, in general, form a major part of the freshwater food web, constituting a basic food source for fish. Many of the freshwater species are considered cosmopolitan in nature, largely due to their reproductive strategy of epiphytic eggs. These eggs can withstand considerable extremes of conditions and under suitable conditions will reemerge (Pennak, 1978).

Species of *Bosmina* spp. made up the majority of cladoceros found in the ballast water samples. Many species of this genus are indigenous to the Great Lakes, including the *Bosmina longirostris* specimens from the St. Lawrence River (No. 2) (Davis, 1966; Watson, 1974, 1976; Shih, 1971). In several of

the ballast water samples containing *Bosmina*, the salinities exceeded the levels normally attributed to the most tolerant brackish water species known, *B. coregoni* var. *maritima* (<1.0‰) (Green, 1975). These organisms were considered 'live' in the samples; however, their condition may have been misleading.

The genera *Evadne* sp. and *Podon* spp. are marine forms restricted to the salinities of the St. Lawrence estuary, where representatives currently exist (Shik, 1971; Perkins, 1974). They are unlikely to enter into freshwaters.

Epiphytic eggs were produced by cladocerans under stress conditions, indicating that the ballast tanks were unfavourable habitats in some instances (Nos. 16, 29, 33, 55). In Ship 33, no adult forms were found, only the eggs. If the environment present in the Great Lakes was favourable, active juvenile cladocerans would emerge.

Cladocerans arriving from European waters (Nos. 8, 16, 17, 19, 22, 28, 29, 30, 40, 45) may be considered different from their North American counterparts. Recent taxonomic developments have revealed some anomalies between shared species of Europe and North America (Watson, 1981). This is also true for *Acroperus* sp. from the Mediterranean Sea (No. 37).

Cladocerans, in general, are not problem organisms. Therefore, the main impact which foreign species would impart on the Great Lakes may be competition with native species and the subsequent effect on the food web.

2.9 Ostracoda

Ostracods are freshwater and marine organisms, about 30 of which are capable of tolerating salinity changes from 0.05‰ to more than 2.0‰ (Green, 1975; Perkins, 1974). The majority of Ostracods are free-living or bottom dwelling (Green, 1975; Pennak, 1978), and a few species are parasitic on crayfish. The relatively cosmopolitan distribution of many genera and species is attributed, like the Cladocerans, to their parthenogenic reproduction.

In the ballast water samples, most of the 'live' Ostracods were from marine or estuarine samples (Nos. 11, 15, 24, 25, 30). Only one sample (No. 40), from the Nile region of the Suez Canal, contained a 'live' freshwater form.

While the importation via ballast waters of foreign species into the Great Lakes is quite probable, their impact is not readily assessable. Little information is known of Ostracod ecology but only a few appear to be regarded as problem organisms.

In addition to the parasitic species which attack crayfish, a few are known to be an intermediary host of Acanthocephala which parasitizes fish (Pennak, 1978). It is estimated that, at present, only a small percentage (<2%) of the Ostracods in the Great Lakes are infected with the parasites of this phylum. There is the possibility that new nonendemic parasites of Acanthocephala could enter the Great Lakes via foreign Ostracods. However, it would be necessary for the parasite to adapt and find a suitable final host before it could become established. More research will be required before the above process can be demonstrated.

2.10 Copepoda

All of the Copepods sampled were free-living, non-parasitic species, belonging to the suborders Calanoida, Cyclopoida and Harpacticoida. Estuarine and freshwater forms originating from European waters are probably not endemic species. Recent taxonomic developments have indicated a level of discontinuity between organisms of identical species classification, from European and North American waters, suggesting that the organisms are actually different (Watson, 1981).

The marine forms found in the ballast water samples, *Corycaeus* spp., *Euterpina* spp. and *Paratylalestris croni* are not endemic to the Great Lakes or the estuarine areas (Bousfield and Laubitz, 1972; Shih, 1971; Watson, 1974). They would be

restricted to the estuary, however, as marine copepod forms are immobilized at low salinities (Green, 1975).

The presence of 'live' nauplii and eggs indicated that the populations transported in the majority of ballast tanks were viable and reproducing, ensuring that some survived to be introduced. The potential for foreign copepods to be introduced, therefore, appears inevitable, based on the fact that 78% of the ships sampled carried viable forms, attesting to the broad distribution and durability of these organisms. Also, the Great Lakes, at present, contain only a very small number of the total freshwater copepods present worldwide.

The invasive potential of foreign species into the Great Lakes has been demonstrated by the case of a suspected past introduction. A euryhaline calanoid copepod, *Eurytemora affinis*, was first recorded in Lake Erie in 1960 (Engel, 1962). It has since spread to the rest of the Great Lakes and now comprises an appreciable part of the copepod population (Watson, 1974). However, little information has apparently been gathered on the ecological impact of this species, apart from its having become established. It is also doubtful that researchers have the necessary tools and information to accurately assess its impact at the present time (Watson, 1981).

Parasitic forms of copepods will also be subject to introduction, with Cyclopoida and Harpacticoida, the two dominant

suborders with parasitic representatives in the Great Lakes. The other entirely parasitic orders, Caligoida, Cergulus and Cernaepodoida also have some freshwater representations, few of which are currently present in the Great Lakes. Under natural conditions, these organisms have little potential to cause severe damage to the host fish populations due to their low population levels. However, these parasites would have a substantial effect in fish hatchery operations, where the high population densities of potential hosts would allow the parasites to proliferate, leading to massive infections, often requiring the elimination of the entire fish stock to eradicate the parasite (Pennak, 1978).

Few marine parasite forms would be expected to survive the transition from salt to fresh water. Studies have shown that these organisms, due to osmotic problems, tend to fall off host fish as they reenter fresh water from the marine environment (Green, 1975). Freshwater forms introduced would have their survival and impact dependent on their ability to find a suitable host.

2.11 Cirripedia

Cirripedia, or barnacles, are strictly marine in nature, although some species are capable of tolerating reduced

salinities. (Perkins, 1974). They are present in the zoo-plankton and open water only in their immature forms (nauplii). As adults, they become sessile and foul ships and bottom soil surfaces.

Elminius modestus and *Verruca* sp. nauplii were the only species sampled and are not endemic to either the Great Lakes or the St. Lawrence estuary (Shik, 1971). These are both potential nuisance organisms in the estuary where they would exist as fouling species as adults on ships and harbour structures (Perkins, 1974). They are, however, immobilized at salinities below 1.2‰, a condition which results in death and effectively restricts them from the Great Lakes (Green, 1975; Perkins, 1974).

The presence of *Elminius* in many of the ballast samples is particularly significant. This is an invasive species which originated in Australasia and spread (probably in ballast water) to Europe where it became established, displacing some native species such as *Balanus balanoides* (Elton, 1975; Perkins, 1974) from the northern European coast to the Atlantic Coast of Portugal. *Elminius* appears to have extended its range to the Mediterranean Sea (No. 17) and the Baltic Sea (No. 48) from where it has not been recorded previously (Green, 1975; Perkins, 1974). Its establishment in the St. Lawrence estuary

may be imminent. The competitive advantages of *Elminius* include its ability to withstand low salinities and its prolific reproductive habits - it is often capable of reproducing while other species are not. As a result, this barnacle can make the most use of the available habitat before its competitors can react.

2.12 Mysidaceae

The Mysidacea, or opossum shrimps, are comprised of almost exclusively marine species, although some brackish species and very few freshwater forms exist (Meglitsch, 1972; Pennak, 1978). Both *Neomysis* spp. and *Mesopodopsis slabberi*, identified in the ballast water samples are low salinity tolerant marine forms. *Neomysis* spp., in particular, is capable of penetrating deeply into areas of low salinity and has been observed to survive in freshwater for several days (Perkins, 1974; Green, 1975). *Neomysis* presently has representatives in the St. Lawrence estuary (Shih, 1971), although it is not endemic to the Great Lakes. *Mesopodopsis slabberi* cannot penetrate nearly as far, being limited to salinities greater than 0.15‰ and to higher levels for reproduction (Perkins, 1974; Green, 1975). It is not reported in the estuary area at present (Shih, 1971) and is not endemic to the Great Lakes. Only one species of freshwater mysid occurs

in the Great Lakes, *Mysis oculata relicta*, which is widespread and occurs in Northern European cold water lakes (Pennak, 1978; Davis, 1966).

The introduction of another freshwater form into the Great Lakes may not be detrimental. *Mysis* is a very important component of lake trout diet and, as such, several transplant programs in Western Canada, United States, Sweden and Russia are known to have successfully taken place.

For a species such as *Neomysis* spp. to become established in the Great Lakes, it would have to be deposited in an area of elevated salinity to ensure its reproductive capability and where the hypolimnial water temperature did not exceed 14°C for an extended period of time (maximum tolerable temperature for mysid shrimp). These parameters would exclude Lake Erie, where the native *Mysis* is in decline due to the lake's eutrophication process (Davis, 1966; Cook and Johnson, 1974). *Neomysis* has occurred in California where *N. mercedis* now occupies freshwater lakes and rivers near the coast (Pennak, 1978), where they still have connections to salt water.

2.13 Isopoda

The Isopoda were represented by three individuals, two of which were identifiable. One was a marine species, *Idotea*

baltica which originated from the Atlantic Coast of the British Isles (No. 29). *Idotea* is currently endemic to the outer St. Lawrence estuary (Shih, 1971) but not the Great Lakes. This species is restricted from the Great Lakes by its salinity requirements (Perkins, 1974). The second species identified was a freshwater lotic form, *Asellus aquaticus*, the only European species known to migrate into brackish waters (Green, 1975; Perkins, 1974). *Asellus* is known to tolerate low oxygen conditions and in organically polluted streams will move into the riffle areas, replacing less tolerant species (Hawkes, 1979). *Asellus* is currently not endemic to the Great Lakes (Pennak, 1978), but if it survives introduction, it could establish itself in river systems.

The Great Lakes support a very poor variety of Isopods, comprised primarily of *Lirceus lineatus*, *Asellus militarus*, and *Asellus recovitzai* (Cook, 1974; Shrivastava, 1974; Pennak, 1978). Pennak (1978) states that all of the North American species are restricted to North America. Therefore, any imported species, including *A. aquaticus* will be a foreign organism. One species, *Sphaeroma terebrans*, is a wood-boring isopod which is responsible for extensive damage to wooden pilings and jetties. Its distribution is presently restricted to tropical regions, and while primarily brackish, it has been reported in fresh-water estuaries in the southern United States (Pennak, 1978; Kaestner, 1970). Successful introduction of

this species to the lower estuary of the St. Lawrence would probably require the existence of a warm water effluent to match its normal thermal environment.

Isopods also appear as parasites, primarily on fish and crustaceans from which they ingest blood. Few species, however, are recorded from freshwater.

2.14 Amphipoda

The amphipod representative sampled in the ballast waters was a marine skeleton shrimp - *Caprella* sp., which originated from the Adriatic Sea (No. 37). In comparison with species endemic to the Canadian Atlantic Coast (including the Gulf of St. Lawrence and estuary), this specimen is not endemic, because it did not match any of the species cited by Laubitz (1972). The condition of the specimens suggests that this organism is capable of surviving for at least 15 days of low salinity (0.1‰ in the ballast water).

In comparison to the world totals of freshwater amphipods, Great Lakes' amphipod populations are particularly poor. Only about 10 species regularly occur in the Great Lakes, compared to the 80 species in the United States and 800 species worldwide (Pennak, 1978). The potential for introduction of new species

is quite large and includes such European genera as *Niphargus* a very large group which does not occur in North America (Pennak, 1978).

2.15 Diptera

Most of the Dipteran species found in the ballast water samples were adult Chironomidae belonging to the tribe Chironomini, which includes the common estuarine genera *Chironomus* spp. and *Cricotopus* spp. The specimens were not identifiable to the genus level due to the damaged condition of several important taxonomic features. However, both *Chironomus* spp. and *Cricotopus* spp. are known in the Great Lakes and may be indigenous to at least the estuarine regions. The presence of egg-bearing females in the ballast water samples increased the potential for the organism's introduction. Adults only live for the few days necessary to reproduce (Pennak, 1978); therefore, introduced species would probably enter as larvae. The larval forms collected were a *Tanytarsus* individual and a specimen belonging to the tribe Orthodadiini. *Tanytarsus* are indigenous to the Great Lakes and estuarine areas (Cook and Johnson, 1974). The Orthocladiini is potentially marine in origin although its condition did not permit an accurate determination. Ship No. 42, which originated from Rotterdam, Holland, had a salinity of 2.1‰. As such, it would not be endemic to the Great Lakes or likely to survive the salinity change.

The indigenous species of the Great Lakes are a major food source in some locations (Pennak, 1978). Whether food webs would be disrupted by the introduction of new species is unknown. However, the most obvious potential problem might originate with the successful introduction of the Culicidae (mosquitoes) which are responsible for the transmission of numerous diseases (i.e. malaria).

2.16 Decapoda

The presence of penaeid nauplii in the ballast water indicated that adult decapods may have been reproducing no more than 24 hours prior to the sampling of the ballast tanks. Penaeid larvae pass through this stage within 24 hours (Newell and Newell, 1977), after which they obtain their normal naupliar characteristics. Their condition, small size, and state of development made further identification impossible.

Penaeida are basically marine although some species can tolerate low salinities in estuaries (Gosner, 1971; Green, 1975). Some southern United States species are capable of penetrating to 0.04‰ as immature forms. Adult forms must return to the sea to breed, however; making it unlikely that a reproducing population could become established in the Great Lakes. What impact foreign decapods may have in

lakes and estuary is uncertain, although many of these species are valued commercially in Europe and North America.

Species of Porcellanidae (porcelain crabs) were also found in the ballast water samples. *Porcellana* are not endemic to the estuary or Great Lakes (Shih, 1971; Bousfield, 1975) being primarily marine species which are rarely found inshore (Newell and Newell 1977; Gosner, 1971). Their successful introduction into waters less saline than the outer estuary is doubtful because of their inability to osmoregulate in low saline waters.

One species of Decapod which is known to be a problem in northern China and more recently Europe, is the Chinese Mitten Crab, *Eriocheir sinensis*. This species was originally introduced to northern European coastal waters from China in 1912 (Elton, 1975). Since then, they have spread rapidly along the coast from the English Channel into the eastern Baltic Sea and have penetrated deeply into several rivers. *Eriocheir* was recently found in Lake Erie in 1973, the Detroit River in 1965 (Nepszy and Leach, 1973) and in Ohio waters in 1975 (Leach, 1981). It is believed to have been introduced through ballast water discharge. The significance of this lies in the destructive habits of the adult crab which

burrows into stream banks causing extensive erosion, damages nets, eats bait and netted fish and reduces potential fish food (Nepszy and Leach, 1973), adding up to appreciable ecological and economic impact. It is also known to bypass obstacles such as dams and survive in wet meadows for up to 38 days (Kaestner, 1970). While it is not likely to become reproductively established in the Great Lakes, it could establish in the estuarine area (Nepszy and Leach, 1973 and Leach, 1981), where it can reproduce. The adults are reported to migrate long distances upriver (up to 750km) from estuary areas, which would enable them to enter Lake Ontario, then return to the estuary only to breed.

2.17 Chaetognatha

The Chaetognathans are a strictly marine group. *Sagitta* sp. is a pelagic predatory organism which is sometimes found in estuaries, but usually only when there has been some intrusion of seawater (Perkins, 1974). In the Baltic Sea, where surface salinities are about 1.0‰, *Sagitta* is restricted to the lower depths where salinities are higher. Several species are endemic to the estuarine area of the St. Lawrence (Shih, 1971). The damaged condition of some critical identification features does not allow the determination of the ballast water species and whether they are endemic. Chaetognatha

will not be able to enter the Great Lakes due to their salinity requirements which generally apply to all of the members of this small phylum (Perkins, 1974; Green, 1975; Newell and Newell, 1977).

1.1 Diptera

The adult *Phoridae* species, represents a family of flies common in North America where it is associated with decaying material. They are 1/2" to 1/4" long. The species sampled was found in a large amount of decaying material accumulated on the side of the river. It is possible that there were other species of *Phoridae* present but they were not collected.

1.2 Hemiptera

The *Coreidae* species belongs to the family *Coreidae*, a terrestrial group of which many species are collected, collected from plants and sources of plant material (Green and Newell, 1976). This particular individual may not be indigenous, which it originated from Scotland (Newell).

3. TERRESTRIAL ORGANISMS

There were a few organisms found in the ballast water samples which are not part of the aquatic fauna at anytime during their life cycle. Their occurrence in the ballast water is probably accidental. They are mentioned for the sake of completeness since they represent a potential introduction to North America of foreign terrestrial fauna (Table 19).

3.1 Diptera

The adult Phoridae samples, represents a family quite common in North America where it is associated with decaying material. Ship No. 12, from which this organism was sampled was found to contain a large amount of fecal material encrusted on the sides of the tanks. If these organisms were in association with this fecal material, it is possible that these flies could serve as vectors of diseases from the sampled area (Dominican Republic).

3.2 Homoptera

The Homopteran sampled belonged to the family Aphididae, a terrestrial group of which some species are serious, cultivated plant pests and vectors of plant diseases (Borror and Delong, 1976). This particular individual may not be indigenous, since it originated from Scotland (No. 1).

3.3 Psocoptera

Liposcelidae, or booklice, are a nuisance terrestrial insect which feeds on the starchy materials in books (Borror and Delong, 1976). This group is widespread and although it originated from the Caribbean (No. 5), it is likely indigenous to North America.

3.4 Collembola

The *Isotoma* individual probably originated from the Marseille area of Mediterranean France (No. 41). It is a semi-aquatic form, occurring along coastlines (Pennak, 1978; Green, 1975) in association with vegetation. Species of *Isotoma* and other Collembola are indigenous to the Great Lakes area (Pennak, 1978) and do not appear to present any serious problems. The impact of any new species cannot be assessed.

SUMMARY AND CONCLUSIONS

A total of 55 ship ballast waters, representing 10 geographic regions of origin in the world, were sampled as the vessels entered the St. Lawrence-Great Lakes system. The water quality of the ballast waters, characterized by combinations of pH, oxygen, temperature, salinity and BOD₅ was within a normal accepted range that would not inhibit a broad range of aquatic organisms from surviving in the tanks. Total coliform and Fecal Streptococci counts were all below maximum permissible levels. Even a ballast water containing raw sewage waste (from the Dominican Republic) had acceptable bacterial counts. However, the presence of raw sewage waste in ballast tanks suggests that a potential health hazard may exist if this material is deballasted into the Great Lakes at populated regions.

The major component of this study consisted of the identification and enumeration of aquatic flora and fauna found in the ships' ballast tanks, and the assessment of the potential for impact of these organisms on the Great Lakes system if released. Aquatic organisms were found in each of the ballast water samples examined. Based on the recorded salinity for each sample, the organisms originated from a wide variety of geographic regions and habitats.

The majority (65%) of samples were from the marine environment; 31% were of estuarine origin; and, the remaining 4% were from fresh water.

One of the major problems of this study involved the determination of the actual origin of a particular organism in terms of salinity and geographical location. In several instances, the possibility of ballast water mixing from more than one location complicated the necessary use of regionally applicable taxonomic references. Some samples of low salinity contained a mixture of marine, brackish and tolerant freshwater species, although only one location was given by ship personnel for the origin of the ballast water. A more complete record of ballast water uptake by geographic location is definitely indicated.

Of the aquatic flora present in the samples, the macrophytic component consisted of plant fragments which were insufficiently intact to identify. They were not viable specimens. The remaining plant material in the ballast samples consisted mainly of net plankton, although some nannoplankton was present. Phytoplankton were found in 49 of the 55 samples and at least one potentially viable algal organism had survived transport in the ballast tank

of each vessel. Over 150 species of phytoplankton, representing most divisions and classes, were identified in the samples.

Many of the phytoplankton were identified as being endemic to the Great Lakes. Some phytoplankton, especially those of marine origin, were believed to be incapable of surviving in the Great Lakes or even in the St. Lawrence estuary because of their inability to tolerate low salinity levels. However, a number of foreign phytoplankton species found are believed to be nonendemic to the Great Lakes but have the potential, if conditions are suitable, to survive in freshwater. The species included the following:

<i>Melosira</i> sp.	<i>Euglena</i> spp.
<i>Chaetophora</i> sp.	<i>Tribonema</i> spp.
<i>Scendesmus crassus</i>	<i>Chroomonas</i> spp.
<i>Ankistrodesmus falcatus</i>	<i>Rhodomonas</i> spp.
<i>Elaktothrix</i> sp.	<i>Cryptomonas</i> spp.
<i>Pediastrum boryanum</i> (var.)	<i>Agmenellum thermale</i>
<i>P. duplex</i> (var.)	<i>Anabaena oscillaroides</i>
<i>P. simplex</i> (var.)	<i>Anacystis aeruginosa</i>
<i>P. spp.</i> (var.)	<i>A. marina</i>
<i>Cladophora</i> sp.	<i>A. montana</i>
<i>Ulothrix</i> spp.	<i>Aphanocapsa rivularis</i>
<i>Mougeotia</i> spp.	<i>Microcystis viridis</i>
<i>Spirogyra</i> spp.	<i>Oscillatoria lutea</i>
<i>Staurastrum</i> spp.	<i>Sprulina subsala</i>
	<i>Rhodocorton</i> spp.

These organisms represent phytoplankton which have been associated with a wide range of environmental impact problems. Some are attached species, generally associated with covering and fouling problems (*Anacystis*, *Chaetophora*, *Cladophora*, *Mougeotia*, *Spirogyra*, *Ulothrix*). Others clog filters and screens (*Melosira*, *Mougeotia*, *Spirogyra*, *Tribonema*, *Ulothrix*) or produce slimes (*Anabaena*, *Ankistrodesmus*, *Chroomonas*, *Cryptomonas*, *Elaktothrix*, *Euglena*, *Microcystis*, *Oscillatoria*, *Rhodomonas*, *Spirogyra*, *Staurastrum*, *Ulothrix*). A few cause the discolouration of water (*Chroomonas*, *Rhodomonas*, *Staurastrum*, *Ulothrix*) or affect water quality by imparting a taste or odour (*Anabaena*, *Cryptomonas*, *Microcystis*, *Spirogyra*, *Staurastrum*). Several species are common in eutrophic waters (*Anabaena*, *Euglena*, *Microcystis*, *Mougeotia*, *Oscillatoria*, *Pediastrum*, *Spirogyra*, *Spirulina*, *Staurastrum*) in polluted freshwater (*Anacystis*, *Ankistrodesmus*, *Cryptomonas*, *Euglena*, *Melosira*, *Pediastrum*, *Tribonema*, *Ulothrix*), and one is common in polluted estuaries (*Chroomonas*). All produce significant blooms or are indicators of pollution tolerance and/or adaptability. *Euglena* and *Microcystis* are known indicator species. And finally, two genera (*Anabaena*, *Microcystis*), represent freshwater organisms capable of producing toxins.

Nonendemic marine species in the ballast samples, that are not capable of remaining viable in the Great Lakes, but

have the potential to become established in the St. Lawrence estuary were also found, and included the following:

<i>Belleriochea</i> sp.	<i>Hannaea</i> arcus
<i>Biddulphia</i> spp.	<i>Hydrosera</i> spp.
<i>Campylodiscus</i> spp.	<i>Triceratium</i> spp.
<i>Corethon</i> sp.	<i>Leptocylindricus</i> danicus
	<i>Thallasionema</i> sp.

According to the literature, some phytoplankton are capable of producing autoantagonistic and heteroantagonistic toxins with respect to other plants (i.e. *Pediastrum*, *Scenedesmus*, *Dinophytes*), and paralytic shellfish poisoning in man (i.e. *Dinophytes*). Others, especially members of the Chaetophoraceae may have foreign myxomycetes associated with their slime covering. A number of species are parasitic either on other plants, invertebrates or fish; however, most of these are marine *Dinophytes* incapable of surviving in fresh water.

The assessment of the invasive potential of foreign phytoplankton has been complicated by the physiological and morphological capabilities of some species. Morphological adaptations and plasticity has allowed some marine species, previously thought to be obligotrophic, to invade freshwater

environments. Other organisms in marine and fresh water are, after extensive research, found to be conspecific. Still other organisms have combined or paired to produce interspecific hybrids which confound the problem.

The high percentage of viable organism in the ballast samples has demonstrated the ability of many phytoplankton to persist under adverse environmental conditions. The Volvocales, for example, form zygotes and akinetes, when stressed, which can sustain the species in a suspended state until conditions improve. Alternatively, the ballast tanks may have provided a relatively stable environment conducive to reproduction and proliferation. The water quality results tend to support this conclusion.

The study examined organisms representing almost all of the phytoplankton classes, including the nanoplankton. However, the sampling program was not intended to capture representative nanoplankton species. Therefore, this group of organisms received only a cursory examination.

Nanoplankton are one of the least researched groups in the phytoplankton biota. For much of the world, little or no information is available on this group (Chapman and

Chapman, 1973). Recently, however, studies on the Great Lakes biota have included this fraction (Gladish and Munawar, 1980; Munawar and Burns, 1976; Munawar and Munawar, 1975, 1978, 1979; Munawar et al, 1974, 1978).

Nannoplankton are the most significant component of the algal population, often representing 57-80% of the total biomass. They are often the dominant force in community metabolism, capable of a total photosynthetic output of 87-94% of all primary productivity. In the water column, they are more evenly distributed both vertically and horizontally than the netphytoplankton, and seasonal distribution is also considered to be more uniform. It is also suggested that nannoplankton are more tolerant of extreme environmental changes and conditions than netphytoplankton (Munawar and Munawar, 1975; Munawar et al, 1978).

Tolerance to environmental stress may indicate a unique degree of adaptability for incoming species. Ecologically, changes in community composition at the nannoplankton level could be much more significant than those at the netphytoplankton level (Munawar, 1981).

Until recently, it would have been impossible to determine whether a nannoplankton species was endemic to the Great Lakes.

However, with recent information available on community structure for this size fraction, it may now be possible to monitor incoming ballast waters and determine the extent of foreign species introduction.

The aquatic fauna identified in the samples consisted entirely of invertebrate species. Forty-nine of the 55 samples had at least one viable organism present. Over 56 aquatic species were identified, the majority of them being zooplankton.

Of the freshwater species identified, only a few were not considered to be endemic to the Great Lakes system:

Bosmina spp.

Acroperus sp.

Assellus aquaticus

None of these is regarded as a known problem organism. The Cladocerans, *Bosmina* and *Acroperus* are common genera of the Great Lakes zooplankton, forming an important part of the food web. What impact a foreign species would have is highly speculative, considering the paucity of ecological data and knowledge available concerning these organisms.

The isopod, *Assellus*, is currently nonendemic, and in European lotic waters is indicative of organic pollution and

low oxygen levels. These features would allow this species to establish itself in polluted river systems, replacing less tolerant native species. However, any interpretation of the overall impact of such an establishment would require more extensive research.

A number of organisms belonging to the representative invertebrate orders could not be identified because of poor condition. However, as a group, they have the potential to become established in the Great Lakes, but their status of endemism cannot be determined. The impact of a foreign species introduction would be difficult to assess, particularly for the zooplankton, because the available ecological information and assessment techniques do not provide a significant basis for conclusions. In most instances, the effects of a foreign species introduction would be reflected by its ability to compete with the native species and any subsequent displacement and disruption of the lake community structure.

There does exist considerable opportunity and means for species to survive in ballast transport and enhance the chances of introduction. The presence of Cladoceran epiphytic eggs which are produced under unfavourable conditions, viable egg-bearing copepods and Chironomid female adults, and very young

Penaeid nauplii, indicate that in many cases the organisms in the ballast water were capable of reproducing in transit, and therefore, ensuring that viable organisms were present when introduced. Other organisms which are capable of forming resistant eggs, spores or cysts, such as parasitic nematodes and protozoa in particular, may have these viable forms present in the ballast tanks. However, they would reside in the bottom sediments which in this study were not sampled.

The remaining taxa only had marine representatives present in the samples, although freshwater forms do exist. Some of these taxa contain species which are known problem organisms which would be capable of establishing themselves in the Great Lakes area (e.g. *Dreissenia polymorph*, *Eriocheir sinensis*).

Several of the marine taxa sampled are not endemic to the Great Lakes, and their establishment under normal circumstances would be restricted to the St. Lawrence estuary, primarily because of their inability to osmoregulate in low salinity water at some stage of their life cycle. The taxa included two known problem barnacle species:

Eliminius modestus

Verruca sp.

The presence of *Elminius modestus* in the samples is very significant because it signifies a further extension of its range into the Mediterranean and Baltic Seas and the St. Lawrence estuary after its initial invasion of European waters from Australasia. *E. modestus* is a fouling organism found on ships, harbour structures and bottom substrata.

Several other species were found which are not endemic to the Great Lakes and would be restricted to the St. Lawrence estuary. None of the following is known to be a problem organism in their native habitat, but should not be ignored:

Corycaeus anglicus

Corycaeus spp.

Euterpina acutifrons

Euterpina spp.

Parathalestris croni

Mesopodopsis slabberi

Caprella sp.

Porcellana longicornis

Porcellana sp.

The ecological impact of the introduction of any of these species would be expressed in a manner similar to their freshwater counterparts (i.e. through competition and potential displacement).

The estimated total number of each species present in the ballast water of each ship ranged between 10^4 and 10^9 . This would appear to be sufficient, assuming that a majority of the species survive, for those species requiring sexual pairing for reproduction to successfully find mates. How many individuals are required to overcome the problem of spatial density distribution requirements for successful pairing has never been determined. Asexual reproduction (parthenogenesis, fission) would eliminate this problem. A successful population, therefore, could conceivably be started with a few individuals. The survival of the species would depend on its ability to compensate for possible temperature and salinity shocks and overcome competition and predation.

Even in freshwater, if an area is influenced by a saline effluent, marine organisms are known to be able to survive providing the effluent remains stable (Clemens and Jones, 1954). However, the organisms are restricted to the zone of saline influence. A comparable situation would exist for thermal effluent regions of fresh or marine water. Adult organisms, able to tolerate a wide range of salinity or temperature, may be capable of establishment in the Great Lakes, only returning to zones influenced by saline or thermal effluents during periods of reproduction when tolerance levels are much narrower.

A relatively low number of ballast tanks were sampled in this study over a short period of time (August to October). Only a few ships were sampled for each geographic area and some areas were not represented. The probability of any one particular species being taken up during ballasting operations will depend, in part, on community periodicity. The ballast water will contain only species from the naturally occurring community adjacent to the vessel at that particular time. The presence and abundance of species will be governed by the number of species reproducing at the time and those which have larvae present in the water column. Not all species reproduce at the same time so that the larval populations will vary greatly during the year. Also, species which are reproducing may not be present in the immediate vicinity of the ship during ballast operations. Pelagic adults of some species may be present in the water column at times other than when the vessel is taking on ballast. Their presence will be governed by vertical migration patterns (nocturnal, diurnal), currents, wave action, etc. Only a fraction of the organisms that have the potential to be present throughout the year will be sampled at a given time by one ship (Carlton, 1979; Chesher, 1968; Daroson, 1973). In future, therefore, ballast waters should be sampled throughout the year from any region, particularly those identified as the most potential sources of problem and nonendemic species.

Complete species lists for the Great Lakes and comprehensive ecological data for the assessment of the potential impact of nonendemic species not recognized as problem organisms is necessary. At present, there is insufficient data available to evaluate even the natural zooplankton changes occurring let alone the effects of introduced species (Watson, 1981). The literature also contains examples of seemingly innocuous species becoming pests in their new habitat through unrestrained proliferation. A lack of natural population depressants or the organisms ability to occupy an ecological niche more effectively than a native species allow this to occur. However, to predict the fate of an introduced species to a new habitat will require a thorough knowledge of the ecological requirements of the organism and the ecology of the new habitat.

REFERENCES

- American Public Health Association. 1976. Standard Methods for the Examination of Water and Wastewater. 14th Ed. (1975). A.P.H.A. Publ. Wash. D.C.
- Barnes, R.D. 1974. Invertebrate Zoology, W. B. Saunders.
- Bold, H.C. and M.J. Wynne. 1978. Introduction to the Algae. Prentice-Hall Inc., Englewood Cliffs. N.J.
- Boney, A.D. 1966. A biology of Marine Algae. Hutchinson Educational Ltd., Toronto, Can.
- Borror, D.J. and D.M. Delong. 1976. An Introduction to the Study of Insects. Fourth Ed. Holt, Rinehart and Winston.
- Bourelly, P. 1966. Les Algues D'eau Douce Initiation à la Systematique. Tome I: Les Algues Vertes. Editions N. Boubée & Cie, Paris, Fr.
- Bourelly, P. 1968. Les Algues D'eau Douce Initiation à la Systematique. Tome II: Les Algues jaunes et brunes, Chrysophycées, Phéophycées, Xanthophycées et Diatomées Editions N. Boubée & Cie, Paris, Fr.
- Bourelly, P. 1970. Les Algues D'eau Douce Initiation à la Systematique. Tome III: Les Algues bleues et rouges Les Eugléniens, Peridiniens et Cryptomonadines Editions N. Boubée & Cie, Paris, Fr.
- Bousfield, E.L. and D.R. Laubitz. Stations Lists and New Distribution Records of Littoral Marine Invertebrates of the Canadian Atlantic and New England Regions (1972). National Museum of Natural Sciences Publ. in Biological Oceanography No. 5.
- Braarud, T.; Grearden, K.R. and J. Grontued. 1953. Rapp. adm. Cons. Perm. Int. Explor. Mer. 133:1
- Brewer, E.G. 1941. The fight of the elms. Amer. Forests 47:22-25
- Brunel, J. 1962. Le phytoplancton de la Baie des Chaleurs. Les presses de l'universite de Montréal, Montréal, P.Q.
- Butcher, R.W. 1967. An Introductory Account of the Smaller Algae of British Coastal Waters. Part IV: Chryptophyceae Ministry of Agric., Fish, and Food, Fish Invest., Ser. IV.
- Carlton, J. 1981. Wood's Oceanographic Institution, Wood's Hole, Mass. U.S.A. Personal Communication.

- Caspers, H. 1959. Estratta Dall' Archivio Di Oceanografia e Limnologia 9 (Suppl):153-169.
- Chapman, V.J. and Chapman, D.J. 1973. The Algae. MacMillan, Toronto, Canada.
- Chitwood, B.G. and M.B. Chitwood. 1974. Introduction to Nematology, University Park Press.
- Clemens, H.P. and W.H. Jones. 1954. Toxicity of brine water from oil wells. Trans. Amer. Fish. Soc. 84:97-109.
- Cleve von Euler, A. 1951. Die Diatomeen von Schweden and Finnland. Almquist and Wiksells Boktrycker A.B. Stockholm, Sweden.
- Collins, C.W. 1938. Two elm scolytids in relation to areas infected with the Dutch elm disease fungus. J. Econ. Ent. 31:192-195.
- Cook, D.G. and M.C. Johnson. 1974. Benthic Invertebrates of the St. Lawrence Great Lakes. J. Fish Res. Board Can. 31(5).
- Cooke, M.T. 1928. The spread of the European starling in North America (to 1928). Circ. U.S. Dept. Agr. 40:1-9.
- Davis, C.C. 1955. The Marine and Freshwater Plankton. Michigan State University Press, Mich.
- Davis, C.C. and E.B. Henson. 1966. Plankton Studies in the Largest Great Lakes of the World and a Review of Great Lakes Benthos Research. Univ. of Michigan, Great Lakes Res. Div. Publ., No. 14.
- Dawson, C.E. 1973. Occurrence of an Exotic Eleotrid Fish in Panama with Discussion of Probable Origin and Mode of Introduction. Copeia No. 1.
- De Almeida, F.; Forattini, D. and C. da Silva Lacaz. 1946. Consideracoes sobre tres casos de micoses humanas, de cujas lesoes foram isoladas ao lado dos cogulmelos responsaveis, algas provavamente do genero Chlorella. Ann. Fac. de Med. da Univ. de Sao Paulo 22:295.
- Dussart, B. 1969. Les Copepodes des eaux continentales, Vol. I and II.
- Edmondson, W.T. 1959. Fresh Water Biology. (Ward and Whipple) John Wiley and Sons, N.Y., N.Y.

- Elton, C.S. 1972. The Ecology of Invasions by Plants and Animals. Halsted Press, New York.
- Emery, A.R. and G. Teleki. 1978. European flounder (*Platichthys fleaus*) captured in Lake Erie, Ontario. Cdn. Field Naturalist 92(1):89-91.
- Engel, R. 1962. *Eurytemora affinis*, A Calanoid Copepod New to Lake Erie. Ohio, J. Sci. Vol. 62.
- Farlow, W.G. 1879. Marine Algae of New England and the Adjacent Coast. Reprint. Report of the U.S. Fish and Game Commission.
- Fott, B. 1971. Algenkunde VEB Gustav Fisher Verlag and Jeng., Hamburg, Ger.
- Forestry Commission. 1938. Elm disease. Leaflet. For. Comm. Lond. 19:1-8.
- Forestry Commission. 1950. Chestnut blight caused by the fungus. *Endothica parasitica*. Booklet. For. Comm. 3:1-6.
- Fraser, J.H. 1957. Chaetognatha - Fiches d'indentification due zooplancton. Sheet 1: Cons. int. Explor. Mer.
- Fremy, P. 1972. Cyanophycees des Cotes D'Europe. A. Asher & Co. B.V. Amsterdam, Neth.
- Funk, G. 1927. Die Algenvegetation des Golfs von Neapel. 1978 Reprint by Otto Koeltz Science Publishers. Kennigstein, W. Ger. 350pp.
- Gauvreau, M. 1956. Les Algues Marines du Québec. Jardin Botanique de Montréal. Montréal, P.Q.
- Gibson, R.J. 1978. Behavioural interactions between coho salmon (*Oncorhynchus kisutch*), Atlantic salmon (*Salmo salar*), brook trout (*Salvelinus foninalis*) and steelhead trout (*Salmo gairdneri*) at the juvenile fluviatile stages (Abstract). In Metamek Annual Report for 1978 (ed. Fredrick G. Whoriskey). Woods Hole Oceanographic Institution Technical Report, WHOI-79-49.
- Gladish, D.W. and M. Munawar. 1980. The Phytoplankton Biomass and Species Composition at Two Stations in Western Lake Erie, 1975/76. Into Revue ges Hydrobiol. 65(5):691-708. New York, New York. pp.307-336.

- Gosner, K.L. 1971. Guide to Identification of Marine and Estuarine Invertebrates. Wiley-Interscience. Toronto.
- Graham, H.W. and N. Bronikovsky. 1944. Carnegie Institute Publication.
- Green, J. 1963. A Biology of Crustacea. H.F. & G. Witherby Ltd.
- Green, J. 1968. The Biology of Estuarine Animals. Side-wick and Jackson.
- Hannerz, L. 1961. Polychaeta: larvae Fiches d'identification du zooplankton. Sheet 91: Cons. Int. Explor. Mer.
- Hart, C.W. and S.L.H. Foller. 1974. Pollution Ecology of Freshwater Invertebrates. Academic Press.
- Hasle, G.R. and D.L. Evensen. 1976. Brackish water and freshwater species of the diatom genus *Skeletonema*. II. *Skeletonema potamos* comb. nov. J. Phycol. 12:73-82.
- Huber-Pestalozzi, G. 1950. Das Phytoplankton des Siisswassers. Teil 3. Cryptophyceen, Chloromonadinen, Peridineen. In Die Binnengewässer (Ed., A. Thienemann). Stuttgart. 322 pp.
- Humm, H.J. and S.R. Wicks. 1980. Introduction and Guide to the Marine Bluegreen Algae. John Wiley and Sons Co. Ltd., Toronto.
- Kaestner, A. 1970. Invertebrate Zoology. Vol. II (Crustacea). Interscience (Publ.)
- Kallas, L. 1981. C.C.I.W. Burlington, Ontario. Personal Communication.
- Keeney, W.L.; W.G. Breck; G.W. VanLoon and J.A. Page. 1976. The determination of trace metals in *cladophora glomerata* - *C. glomerata* as a potential biological monitor. Wat. Res. 10:981-984.
- Keup, L.E.; Ingram, W.M. and K.M. Mackenthum. 1967. Biology of Water Pollution. A Collection of Selected Papers on Stream Pollution, Waste Water and Water Treatment. U.S. Dept. Interior, Fed. Water. Poll. Control Admin.
- Kornmann, P. and P.H. Sahling. 1977. Meeresalgen von Helgoland-Benthische Grün-, Braun- und Rotalgen. Biologische Anstalt Helgoland. Hamburg. Ger.

- Lackner, E.A.; Robbins, C.R. and W.R. Courtney, Jr. 1970. Exotic fishes and other aquatic organisms introduced into North America. *Smithson. Contrib. Zool.* 59:1-29.
- Laubitz, D.R. 1972. The Caprellidae (Crustacea, Amphipoda) of Atlantic and Arctic Canada Publications in Biological Oceanography, No.4.
- Leach, J.H. 1973. Seasonal Distribution, Composition and Abundance of Zooplankton in Ontario Waters of Lake St. Clair. *Proc. 16th Conf. Great Lakes Res., Int. Assoc. Great Lakes Res.* pp.54-64.
- Leach, J.H. 1981. Ontario Ministry of Natural Resources Lake Erie Fisheries Research Station, Wheatley, Ontario. Personal Communication.
- Lefèvre, M. 1964. Extracellular Products of Algae. In: *Algae and Man.* (Ed., Daniel F. Jackson). Plenum Press, New York, New York. pp.337-367.
- Leedale, G.F. 1967. Euglenoid Flagellates. Prentice-Hall, Inc., Englewood Cliffs, N.J.
- Levine, N.D. 1968. Nematode Parasites of Domestic Animals and of Man. Burgess Publishing Co. 2nd Edition.
- Link, V.B. 1955. A history of plague in the United States of America. *Publ. Hlth. Monogr., Wash.* 26:1-120.
- Loosanoff, V.L. 1955. The European oyster in American waters. *Science* 121:119-121.
- Lund, J.W.; Kipling, C.I. and E.D. Le Cren. 1958. The inverted microscope method of estimating algal numbers and the statistical basis of estimations by counting. *Hydrobiologia* 11:143-170.
- Marshall, A.J. and W.D. Williams. 1974. *Textbook of Zoology: Invertebrates* 74 The MacMillan Press Ltd.
- McConnaughey, B.H. 1974. *Introduction to Marine Biology*, The C.V. Mosby Co.
- Medcof, J.C. 1975. Living Marine Animals in a Ship's Ballast Water. *Proc. Nat. Shellfishes Assoc.* 65:54-55.
- Meglitsch, P.A. 1972. *Invertebrate Zoology*, Oxford University Press.

- Meneghine, G. 1842. *Alghe Italiane e Dalmatchie*. 1970 Reprint by A. Asher and Co. N.V. Vaals. 384pp.
- Metcalf, H. and J.F. Collins. 1911. The control of the chestnut bark disease. *Farmers' Bull.* U.S. Dept. Agr. 467:1-24
- Ministry of the Environment. 1978. *Guidelines and Criteria for Water Quality Management in Ontario*. Toronto.
- Morton, B.S. 1969. Studies on the Biology of *Dreissena polymorpha* Poll. III - Population Dynamics. *Proceedings of the Malacological Society of London* Vol. 38.
- Munawar, M. and N.M. Burns. 1976. Relationships of Phytoplankton Biomass with Soluble Nutrients, Primary Production, and Chlorophylla in Lake Erie. 1970. *J. Fish. Res. Bd. Can.* 33(3):601-611.
- Munawar, M. and I.F. Munawar. 1975. The Abundance and Significance of Phytoflagellates and Nannoplankton in the St. Lawrence Great Lakes. *Veth. Internat. Verein. Limnol.* 19: 705-723.
- Munawar, M. and I.F. Munawar. 1976. A Lakewide Study of Phytoplankton Biomass and its Species Composition in Lake Erie, April-December 1970. *J. Fish. Res. Bd. Can.* 33(3): 581-600.
- Munawar, M. and I.F. Munawar. 1978. Phytoplankton of Lake Superior 1973. *Int. Assoc. Gr. Lks. Res.* 4(3-4):415-442.
- Munawar, M. and I.F. Munawar. 1979. A Preliminary Account of Lake Huron Phytoplankton, April-December 1971. *Fish. Mar. Ser. Tech. Rpt. No. 917.* 6pp.
- Munawar, M.; Munawar, I.F.; Culp, L.R. and G. Dupuis. 1978. Relative Importance of Nannoplankton in Lake Superior Phytoplankton Biomass and Community Metabolism. *J. Gr. Lks. Res.* Dec. 1978. *Int. Assoc. Gr. Lks. Res.* 4(3-4):462-480.
- Munawar, M.; Stadelman, P. and I.F. Munawar. 1974. Phytoplankton Biomass, Species Composition and Primary Production at a Near Shore and a Midlake Station of Lake Ontario During IFYGL (IFYGL). *Proc. 17th Conf. Gr. Lks. Res.* 629-652. *Int. Assoc. Gr. Lks. Res.*

- National Academy of Sciences, National Academy of Engineering, 1972. Water Quality Criteria 1972. A Report of the Committee on Water Quality Criteria. Environmental Studies Board EPA. R3.73.033, March, 1973. 594pp.
- Naylor, E. 1957. Isopoda-Fiches d'identification du zooplankton, Sheets 77 and 78: Cons. Int. Explor. Mer.
- Nepszy, S.J. and J.H. Leach. 1973. First records of the Chinese mitten crab, *Eriocheirs sinensis* (Crustacea: Brachyura) in North America. J. Fish. Res. Bd. Canada 30: 1909-1910.
- Newell, G.E. and R. C. Newell. 1977. Marine Plankton: A Practical Guide. Hutchinson of London.
- Nicholls, K.H.; Kennedy, W. and C. Hammett. 1980. A Fish Kill in Heart Lake, Ontario, Associated with the Collapse of a Massive Population of *Ceratium hirundinella* (Dinophyceae). F. Biol. 10:553-561.
- North, W.J.; Stephens, G.J. and B.B. North. 1972. Marine Algae and their Relation to Pollution Problems. In: Marine Pollution and Sea Life. (Ed., Mario Ruvio) FAO Tech Conf. Mar. Poll. Effects on Living Res. and Fish. 1970. Rome, Italy. pp.330-340.
- Nouvel, H. 1950. Mysidacea-Fiches d'identification du zooplankton. Sheets 18-27: Cons. Int. Explor. Mer.
- Palmer, M.C. 1977. Algae and Water Pollution. EPA-600/9-77-036 Municipal Env. Res. Lab., Office Res. Dev., U.S. E.P.A., Cincinnati, Ohio.
- Pennak, W. 1978. Freshwater Invertebrates of the United States, John Wiley and Sons.
- Perkins, E.J. 1974. The Biology of Estuaries and Coastal Waters, Academic Press.
- Poulsen, E.M. 1969. Ostracoda-Fiches d'identification du zooplankton. Sheets 115 and 116: Cons. Int. Explor. Mer.
- Prescott, G.W. 1962. Algae of the Western Great Lakes Area, W.M.C. Brown Co., Dubuque, Iowa.
- Prescott, G.W. 1970. How to Know the Freshwater Algae. W.M.C. Brown Co. Publ., Dubuque, Iowa.

- Ralfs, J. 1962. The British Desmidiaceae. Reprint by J. Cramer Weinheim. Hafner Publ. Co., N.Y.
- Rammner, W. 1939. Cladocera-Fiches d'identification du zooplankton. Sheet 3: Cons. Int. Explor. Mer.
- Reid, G.K. and R.D. Wood. Ecology of Inland Waters and Estuaries. 1976. Divan Nostrand Co.
- Round, F.E. 1965. The Biology of the Algae. Edward Arnold Publ. Ltd., London, England.
- Schwimmer, D. and M. Schwimmer. 1964. Algae and Medicine. In: Algae and Man. (Ed., D.F. Jackson). Plenum Press, New York, New York. pp.368-412.
- Segerstiale, S.G. 1964. Oceanogr. Mar. Biol. A. Rev. 2: 373-392.
- Shih, C.-T., E.H. Grainger. A Synopsis of Canadian Marine Zooplankton. 1971. Fisheries Res. Bd. of Canada Bulletin 176.
- Shrivastava, H. 1974. Macrobenthos of Lake Huron Fisheries Research Board of Canada Technical Report. No. 449.
- Sinclair, M. 1978. Summer Phytoplankton Variability in the Lower St. Lawrence Estuary. J. Fish. Res. Bd. Can. 35: 1171-1185.
- Skulberg, O.M. 1964. Algal Problems Related to the Eutrophication of European Water Supplies, and a Bio-Assay Method to Assess Fertilizing Influences of Pollution on Inland Waters. In: Algae and Man. (Ed., D.F. Jackson). Plenum Press. New York, New York. pp.262-306.
- Smith, M. 1950. The Freshwater Algae of the United States. McGraw Hill Book Co., Inc., Toronto, Can.
- Stein, J.R. 1973. Handbook of Phycological Methods - Culture Methods and Growth Measurements Cambridge Univ. Press, Cambridge, Engl.
- Stewart, W.D.P. 1974. Algal Physiology and Biochemistry. Bot. Monogr. Vol. 10. University of Calif. Press., Los Angeles, Calif.
- Stoermer, E.F.; Bowman, M.M.; Kingston, J.C. and A.L. Schaedel. 1975. Phytoplankton and Abundance in Lake Ontario During IFYGL. EPA-660/3-75-004 Nat. Env. Res. Cent., Off. Res. Develop., U.S. E.P.A., Corvallis, Oregon.

- Stofan, E. and C. Grant. 1978. Phytoplankton Sampling in Quantitative Baseline and Monitoring Programs. EPA 600/3-78-025. Corvallis Env. Res. Stn., Off. Res. Dev., U.S. E.P.A., Newport, Oregon. Special Sci. Rpt. No. 85. Virg. Inst. Mar. Sci.
- Taft, C.E. and C.W. Taft. 1971. The Algae of Western Lake Erie. Bull. Ohio Biol. Survey, New Series, Vol. 4(1) - 189 pp.
- Taylor, W.F. 1957. Marine Algae of the North Eastern Coast of North America. University of Michigan Studies, Scientific Series Vol. XIII. The Univ. of Michigan Press. Ann Arbor, Mich.
- Taylor, W.R. 1928. The Marine Algae of Florida with Special Reference to the Dry Tortugas. Carnegie Inst. of Washington. Washington, D.C.
- Taylor, W.R. 1960. Marine Algae of the Eastern Tropical and Subtropical Coasts of the Americas. Univ. of Michigan Press. Ann Arbor, Mich.
- Tarapchak, J. and F. Stoermer. 1976. Enviromental Status of the Lake Michigan Region, Vol. 4. Phytoplankton of Lake Michigan. Argonne National Lab. Environmental Control Technology and Earth Sciences.
- Ulm, A. 1948. The Chinese chestnut makes good. Amer. Forests 54:491, 518, 520 and 522.
- Van den Hoek, C. 1962. Criteria and Procedures in Present-Day Algal Taxonomy. In: Algae and Man. (Ed., D.F. Jackson). Plenum Press, N.Y., N.Y. pp.31-58.
- Van den Hoek, C. 1963. Revision of the European species of Cladophora. E. J. Brille, Leiden, Neth.
- Van den Hoek, C. Colijn, F., Cortel-Breeman, A.M. and J.B. Wanders. Algal Vegetation Types Along the Shores of Inner Bays and Lagoons of Curacao, and of the Lagoon Lac (Bonaire), Netherlands Antilles. North Holland Publ. Co. - Amsterdam, Neth.
- Ward, H.B., G.C. Whipple. 1959. Freshwater Biology. John Wiley and Sons.
- Watson, N.H.F. 1974. Zooplankton of the St. Lawrence Great Lakes - Species Composition, Distribution and Abundance. J. Fish. Res. Bd. Can. 31(5).

- Watson, N.H.F. 1976. Seasonal Distribution and Abundance of Crustacean Zooplankton in Lake Erie, 1970. J. Fish Res. Bd. Can. 31(5).
- Watson, N.H.F. 1981. C.C.I.W. Burlington, Ontario. Personal Communication.
- Werner, D. (Ed.). 1977. The Biology of Diatoms. Bot. Monogr. 13. Blackwell Sci. Publ., Oxford, Engl.
- Wimpenny, R.S. 1966. The Plankton of the Sea. Faber and Faber Ltd.
- Woelkerling, W.J. 1976. South Florida Benthic and Marine Algae: Keys and Comments. Sediments V. Div. Mar. Geol. Geophys. Rosenstall School Mar. Atmos. Sci. - Univ. of Miami, Miami, Fla.
- Wood, E.J. Ferguson. 1954. Aust. J. Mar. Freshwater Res. 5:171.
- Wood, P.H.; Dank, P.T. and R.A. Ellis. 1979. The Mosquitoes of Canada. Diptera: Culicidae. In: The Insects and Arachnids of Canada. Part 6 Biosystematics Res. Inst. Ottawa Publication No. 1686.

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